THE WATER QUALITY of EAGLE (MACHAR) LAKE SOUTH RIVER PARRY SOUND DISTRICT

1979

Ministry of the Environment
Ontario

The Honourable
Harry C. Parrott, D.D.S.,
Minister

Graham W. S. Scott,
Deputy Minister

THE WATER QUALITY

of

EAGLE (MACHAR) LAKE

SOUTH RIVER

PARRY SOUND DISTRICT

NORTHEASTERN REGION

TECHNICAL SUPPORT

and

LABORATORY SERVICES BRANCH

MICROBIOLOGY SECTION

1979

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ACKNOWLEDGEMENTS

The water quality survey of Eagle Lake was a cooperative venture involving the Technical Support Section of the Northeastern Region, and the Microbiology Section of the Laboratory Services Branch.

The authors, S. Janhurst, G. Myslik and A. A. Qureshi wish to acknowledge the contributions of the study participants in the collection of samples, enumeration of bacteriological parameters, preparation of figures and charts, reviews of the draft reports and finally, the typing of the manuscript.

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INTRODUCTION

Eagle, or Machar Lake, is a valuable Central Ontario recreational resource. It sustains heavy use including fishing, boating, swimming and waterskiing while supporting a moderately heavy density of shoreline development.

The concerns of local residents over apparently declining angling success, the appearance of nearshore algae growths and the ability of the lake to absorb additional shoreline development prompted numerous requests for an evaluation of the water quality of Eagle Lake. In response to these requests, a survey defining the chemical and bacteriological water quality was undertaken by the Ministry of the Environment during the summer of 1978. At the same time the Eagle Lake Conservation Association participated in a weekly chlorophyll *a* (algae) and water clarity monitoring program.

Data obtained during the study were used to evaluate the level of existing water quality and to calculate a phosphorus budget for the lake. The potential effect of further housing development on this budget and the projected impact on existing water quality were examined.

STUDY AREA DESCRIPTION

Eagle Lake is situated west of Highway 11 in Machar Township, Parry Sound District. The nearest population centre, the Village of South River, is located approximately 10 kilometres

east of the lake (Figure 1). The largest proximal population centre is the City of North Bay which is 45 kilometres north of South River.

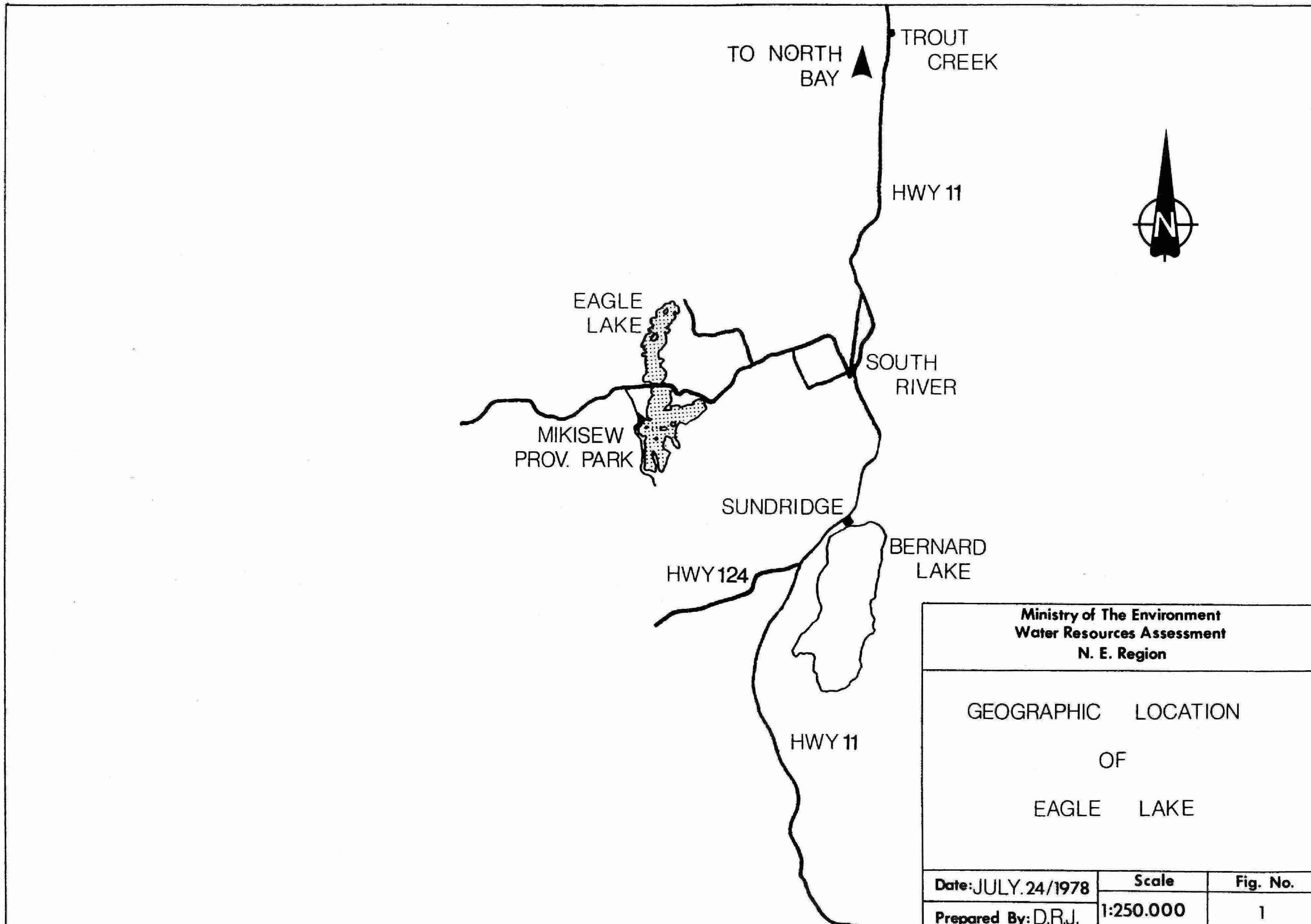
Eagle Lake is a headwater lake of the Magnetewan River watershed which discharges to Georgian Bay in Lake Huron. Its drainage basin covers an area of approximately 3037 hectares and is characterized by rolling and hilly terrain with mixed forest cover.

The surficial geology is dominated by deposits of sand and gravel while boulders and granitic rock outcrops are also visible throughout the drainage basin.

Eagle Lake's physical characteristics are listed below:

Surface Area	991.7 hectares
Maximum Depth	21.9 metres
Mean Depth	6.10 metres
Volume	60.5×10^6 cubic metres

Eagle Lake is divided into two sections by a narrows and bridge located approximately at its middle. The flow is from the north to the south. Both basins can be considered to be separate entities as the narrow and shallow channel between them allows for a very low order of interaction between the basins.



Ministry of The Environment
Water Resources Assessment
N. E. Region

GEOGRAPHIC LOCATION OF EAGLE LAKE

Date: JULY. 24/1978	Scale	Fig. No.
Prepared By: D.R.J.	1:250.000	1

Boating in both northern and southern sections of Eagle Lake has an associated element of risk due to the random distribution of both outcroping and submerged rocks and boulders. There are a number of minor inlets scattered around the perimeter of Eagle Lake. The outlet is the Distress River located at the southwestern end of the lake.

Ministry of Natural Resources statistics show that development on Eagle Lake consists of 311 cottages, 3 resorts, and a 265 unit provincial park (Mikisew).

At present, Ministry of Natural Resources plans are that the lake be managed as a self-supporting smallmouth bass fishery although previous stocking programs have included pickerel, lake trout, brook trout, and rainbow trout.

The main concerns expressed by local residents involved general pollution inputs from the cottages and resorts, surface runoff from area roads, the impact of heavy recreational use and the effect of acidic precipitation on the water quality of Eagle Lake.

SURVEY PROCEDURES

(a) Chemical Water Quality

Up to eight locations on the lake were sampled on four separate occasions during the spring and summer of 1978 (Figure 2). On May 10, composite samples of the euphotic zone (two times Secchi disc visibility which is equivalent to the depth of

EAGLE LAKE CHEMICAL SAMPLING LOCATIONS (1978)

(1) - WATER CHEMISTRY SAMPLING LOCATIONS

CONTOUR INTERVALS IN FEET (1ft = 0.3048 m)

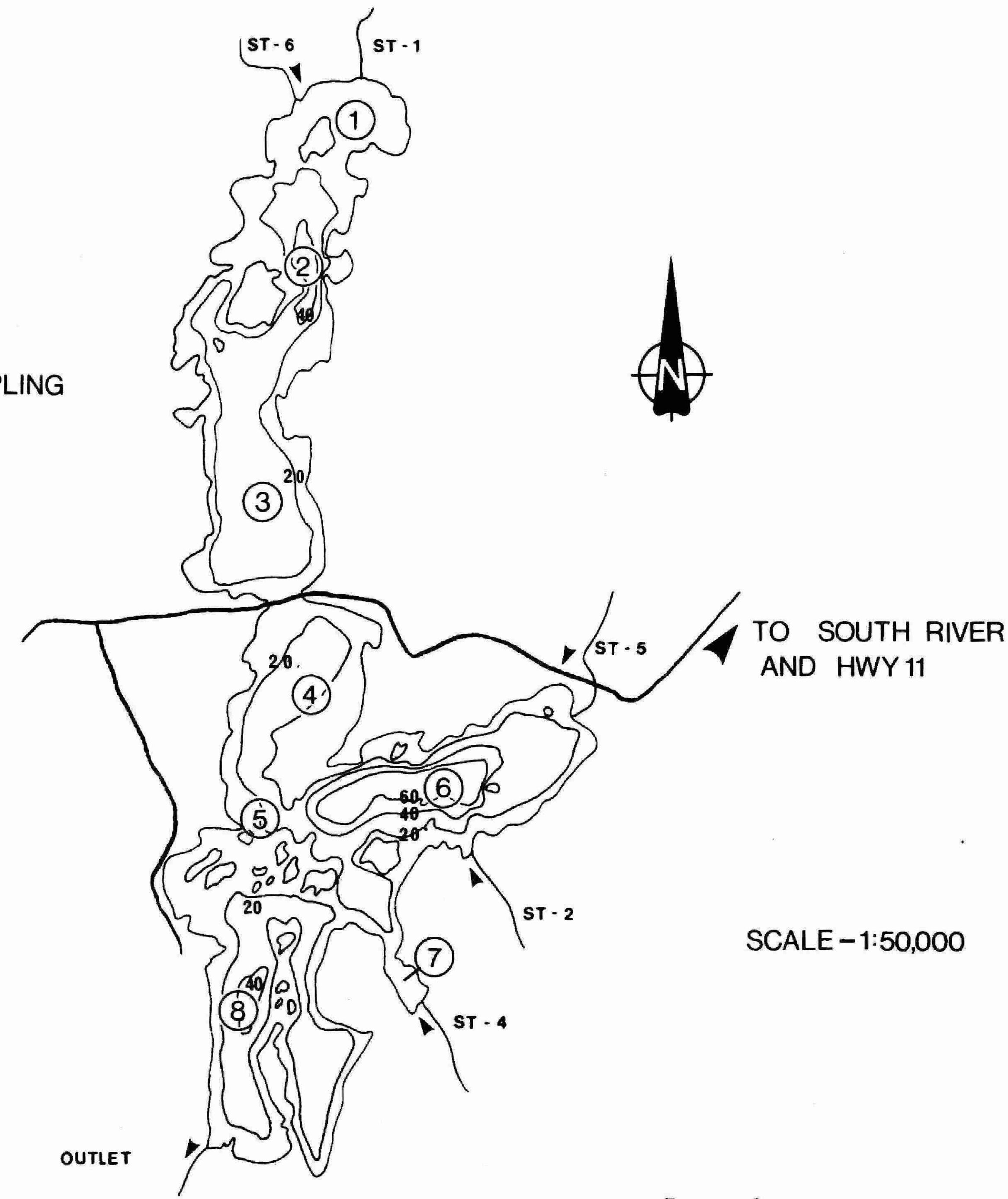


FIGURE 2

effective light penetration) were taken for water chemistry analysis. On June 7, July 11, and August 23, water samples for chemical analysis were obtained through the euphotic zone and one metre off the bottom of the deeper sampling locations designated as 2, 3, 6, and 8 in Figure 2.

Inflowing streams were sampled in July and August.

Chemical analyses performed on water samples included:

hardness	sulphate
alkalinity	total phosphorus
pH	total Kjeldahl nitrogen
conductivity	ammonia
colour	nitrite
calcium	nitrate
magnesium	inorganic carbon
	organic carbon
chloride	iron

The presence of the following heavy metals was also investigated during the June sampling:

copper	lead
nickel	cadmium
zinc	arsenic

Water transparency was measured on twenty separate occasions through the cottager assisted "Self-Help" program and supplemental readings during the chemical sampling days. A Secchi disc (20 cm diameter metallic disc printed in alternate black and white quadrants) was lowered into the water until it disappeared from view. At the same time, water samples for chlorophyll a determination (the green pigment of algae) were secured as euphotic zone composites.

Dissolved oxygen and temperature profiles at one metre depth intervals were developed at the deeper sampling stations (2, 3, 6 and 8).

All chemical analyses were carried out at the Ministry of the Environment laboratory in Toronto.

CHEMICAL TESTS AND INTERPRETATION

The determination of chemical water quality involves evaluation of the concentrations and distribution of particular chemical species. Characterization parameters which are used to "describe" a water include:

Hardness: the soap consuming ability of water.
Calcium and Magnesium: the major cations contributing to hardness.
Conductivity: a measure of the ability of water to pass an electric current. It is used as an indication of quantities of dissolved substances.

pH: a measure of acidic or basic properties of water. A reading above 7 is basic while values less than 7 are acidic.

Colour: a determination of the intensity of the yellow-orange hue contributed to lakes by organic material or iron.

Alkalinity: a measure of a water's ability to resist pH change from acidic inputs.

Nutrient parameters including total phosphorus, the four interrelated forms of nitrogen and inorganic carbon, are used to determine the enrichment or trophic status of a lake. Nutrient poor or oligotrophic lakes are usually very clean and clear while eutrophic or nutrient rich lakes are characterized by turbid water caused by extensive growths of algae and aquatic weeds.

Other chemical species examined are iron and organic carbon which can impart colour, odour and taste to natural water, and chloride and sulphate which can be indicative of pollution inputs resulting from the activities of man.

Where the possible influence of mining or mining-related industrial activity exists, the concentration of heavy metals which can have either chronic or acute toxic effects on plant and animal life are investigated.

Indications of lake trophic status and water quality are also obtained from the investigation of biological and physical conditions.

Primary biological activity is evaluated by measuring the concentration of chlorophyll a, the green pigment in algae (tiny plants suspended in the water column). At the same time, water clarity or transparency is determined by lowering a black and white Secchi disc until it disappears from view.

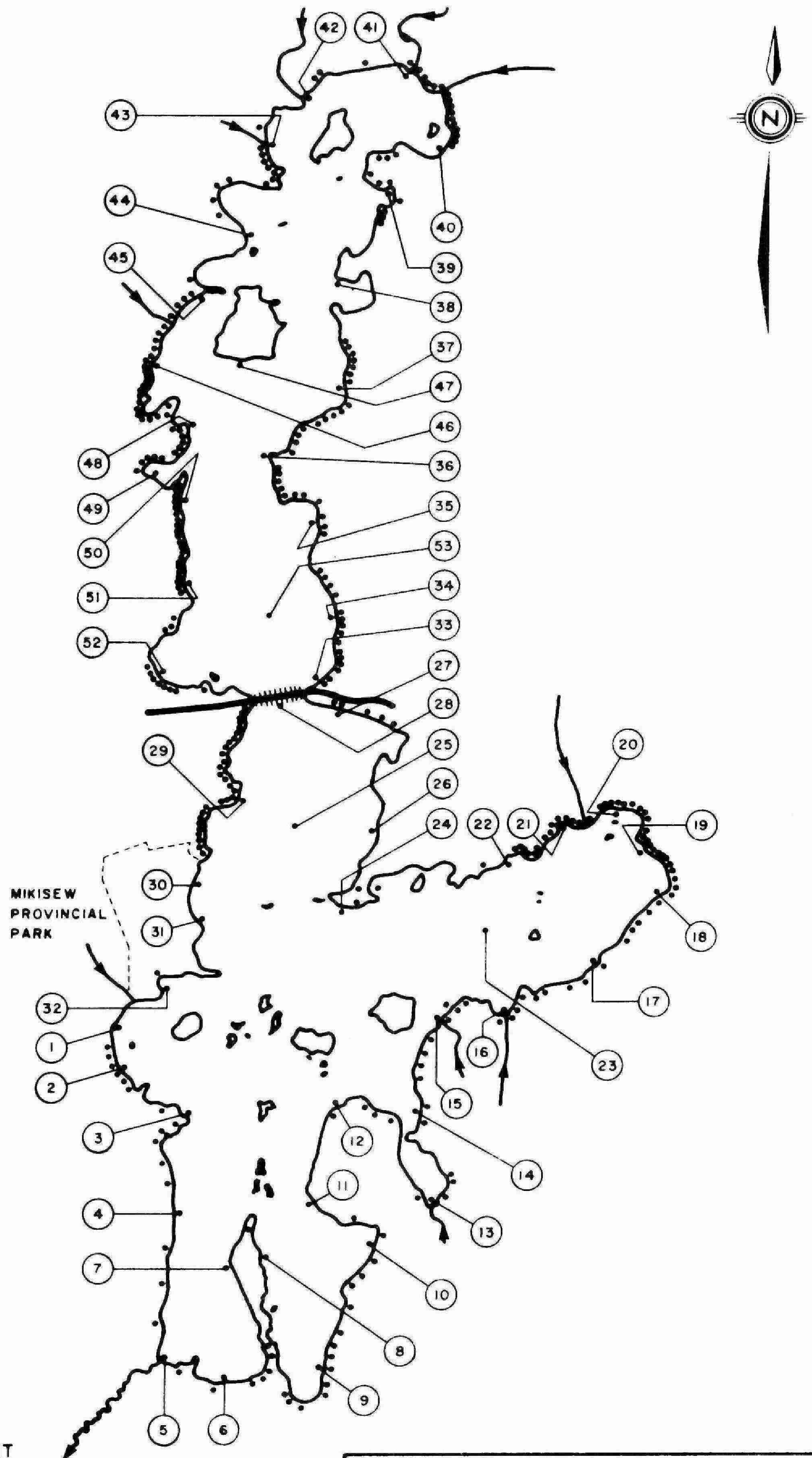
The mid to late summer vertical distributions of dissolved oxygen and water temperature can be used to explain many of the conditions encountered, the type of fishery that can be sustained, and to estimate the potential for the occurrence of specific water quality problems.

(b) Microbiological Water Quality

The southern and northern sections of Eagle Lake were surveyed separately during four day sampling runs conducted from August 17 - 20 and August 21 - 24 respectively.

The microbiological sampling stations were situated along the provincial park, in areas considered representative of the various shoreline developments on the lake, at the inflows, mid-lake and outflow locations. Samples were collected seven to ten metres from the shore and one metre below the surface at 50 shoreline and 3 mid-lake stations (Figure 3). Water samples, obtained manually using presterilized (autoclaved) 500 ml polycarbonate bottles, were stored on ice and transported to the mobile laboratory where they were analyzed within 2 to 6 hours of collection.

FIGURE 3 - LOCATION OF MICROBIOLOGICAL SAMPLING STATIONS AND AREAS OF SHORELINE DEVELOPMENT ON EAGLE LAKE.



LEGEND

(22) — SAMPLING STATIONS

•••• — COTTAGE DEVELOPMENT

1 .5 0 1 KILOMETRES

MINISTRY OF THE ENVIRONMENT

RECREATIONAL LAKES PROGRAM

EAGLE LAKE

1978 WATER QUALITY SURVEY

SCALE: AS SHOWN	
DRAWN BY: ART. S	DATE: MARCH, 1979
CHECKED BY:	DRAWING Nº: 8661

Microbiological Parameters and Methods

All samples were analyzed for the detection and enumeration of pollution indicator organisms (viz. total coliforms, fecal coliforms and fecal streptococci), Pseudomonas aeruginosa and heterotrophic bacteria. In addition, some samples were examined for the presence of Candida albicans.

The three indicator organisms are all indigenous to man and other warm-blooded animals, and are generally found in large numbers in their feces. Since many diseases common to man can be transmitted by feces, the probability of occurrence of these diseases in highest in areas where the water is contaminated with fecal material. These indicator organisms are used in water quality assessment to detect and indicate contamination from fecal material and hence the potential presence of pathogens.

Pseudomonas aeruginosa is recognized as a human (opportunistic) pathogen responsible for a diverse group of diseases including skin and upper respiratory infections and otitis externa, an outer ear infection (Levin and Cabelli, 1972). This organism is also found in feces and can be readily isolated from raw sewage samples. In recent years, P. aeruginosa has also been used as an indicator of fecal pollution (Hoadley, 1968).

Candida albicans (a yeast) constitutes a portion of the body's normal saprophytic microflora, but under appropriate conditions is an opportunistic pathogen causing a number of superficial and skin infections. It is common in human/animal feces and

raw sewage and has been found in both marine and fresh waters. Recently it has been suggested that C. albicans be considered as a potential indicator of water quality (Buck and Bubucis, 1978).

Heterotrophic bacteria are those bacteria which require organic carbon for their growth. The densities of these bacteria in water are influenced by the concentrations of organic nutrients and therefore may be a measure of the degree of organic enrichment in a given body of water.

The densities of total coliform (TC), fecal coliform (FC) and fecal streptococcus (FS) were determined using the membrane filtration (MF) technique. The methods used for the estimation of these pollution indicator bacteria are described in detail in the Ministry of the Environment's "Handbook of Analytical Methods for Environmental Samples", Volume 2, 1976. The levels of P. aeruginosa were ascertained by the MF technique as described by Levin and Cabelli. The MF procedure outlined by Buck and Bubucis was employed for the detection of C. albicans . The levels of heterotrophic bacteria (HB) were obtained using the spot plate technique as described by Young, 1978. For all MF analyses, Gelman GN-6, 47 mm, 0.45 um white, gridded and autoclave-sterilized membrane filters were used.

Statistical Methods

The assessment of water quality cannot be determined accurately from a single water sample as the microbial populations fluctuate tremendously in response to changing environmental conditions. Therefore, microbiological surveys require the

collection of many samples from several stations over a designated period of time (3 to 5 days). The large amount of data generated is reduced by calculations to meaningful and easily managed statistics.

All microbiological data (1072 determinations on 212 samples) collected during the 8-day survey of Eagle Lake were transformed to logarithms (base 10), and all further analyses were done using the transformed data. The geometric mean (the most suitable central value) and variance were calculated for the values of TC, FC, FS, Pseudomonas aeruginosa, and heterotrophs at every station providing concise valid data. These data were then analyzed by a one-way analysis of variance and Bartlett's Test of Homogeneity to determine statistically significant variation in the (microbial) densities between stations or groups of stations. Using this procedure, the data from each station were tested against those of every other station until all stations with similar geometric mean concentrations were separated into individual groups (e.g. Group A, B).

The group results and those for individual stations were identified by different stippling on data summary maps. Within each stippled area, the group geometric mean applied for each type of bacteria at all stations unless otherwise indicated by individual station values. In this manner, significantly different areas of the lake were differentiated as to the degree and level of microbial contamination and related to existing shoreline development or usage.

The effect of present development on the microbiological water quality of Eagle Lake was estimated by comparison of bacterial densities found in developed and undeveloped sections of the lake, and by comparison to bacterial densities in an undeveloped reference lake in Central Ontario.

SURFACE WATER CHEMISTRY CHARACTERISTICS

Results of euphotic zone (surface) water chemistry analyses for May 10 samples are shown in Table 1. Samples were obtained at the four locations designated as 2, 3, 4 and 8 in Figure 2.

Water samples are obtained early in the spring to take advantage of the uniform chemical conditions which exist throughout the lake prior to surface heating and increasing biological activity.

Surface water chemistry data characterize Eagle Lake as a very soft (hardness 11 mg/L), colourless (colour 5), slightly acidic (pH 6.2) lake with a very low load of dissolved substances (conductivity 36 umhos/cm). The buffering capacity to acidic inputs is low (alkalinity 5 mg/L).

Concentrations of the major nutrient elements, phosphorus (0.005 - 0.009 mg/L) and nitrogen (0.3 - 0.4 mg/L) were low and moderate respectively while inorganic carbon levels (1.0 mg/L) were very low.

TABLE 1

SURFACE WATER CHEMISTRY OF EAGLE LAKE

May 10, 1978.

Parameter	Sampling Location			
	2	3	4	8
Hardness	11	11	10	11
Alkalinity	5	6	4	5
pH	6.2	6.2	6.2	6.1
Conductivity	34.5	37.5	35.5	37
Colour	10	5	5	5
Calcium	3.0	3.2	2.8	3.0
Magnesium	.75	.80	.75	.75
Chloride	1.0	1.3	1.7	1.8
Sulphate	7.5	8.0	8.0	8.0
Total Phosphorus	.009	.006	.005	.005
Total Kjeldahl Nitrogen	.26	.018	.016	.020
Ammonia	.028	.018	.016	.020
Nitrite	.002	.002	.002	.002
Nitrate	.135	.110	.095	.110
Organic Carbon	3.0	2.6	2.4	2.3
Inorganic Carbon	1.0	1.2	1.0	1.0

* All concentrations in mg/L except pH, conductivity (umhos/cm) and colour (Hazen units).

The major cations, calcium (3 mg/L) and magnesium (0.76 mg/L) were present in low quantities while concentrations of chloride (1.0 - 1.8 mg/L) and sulphate (8 mg/L) were also low.

TEMPERATURE AND DISSOLVED OXYGEN

Oxygen and temperature profiles for sampling stations 2, 3, 6 and 8 were developed during the June, July, and August sample runs (Figure 4, a, b, c).

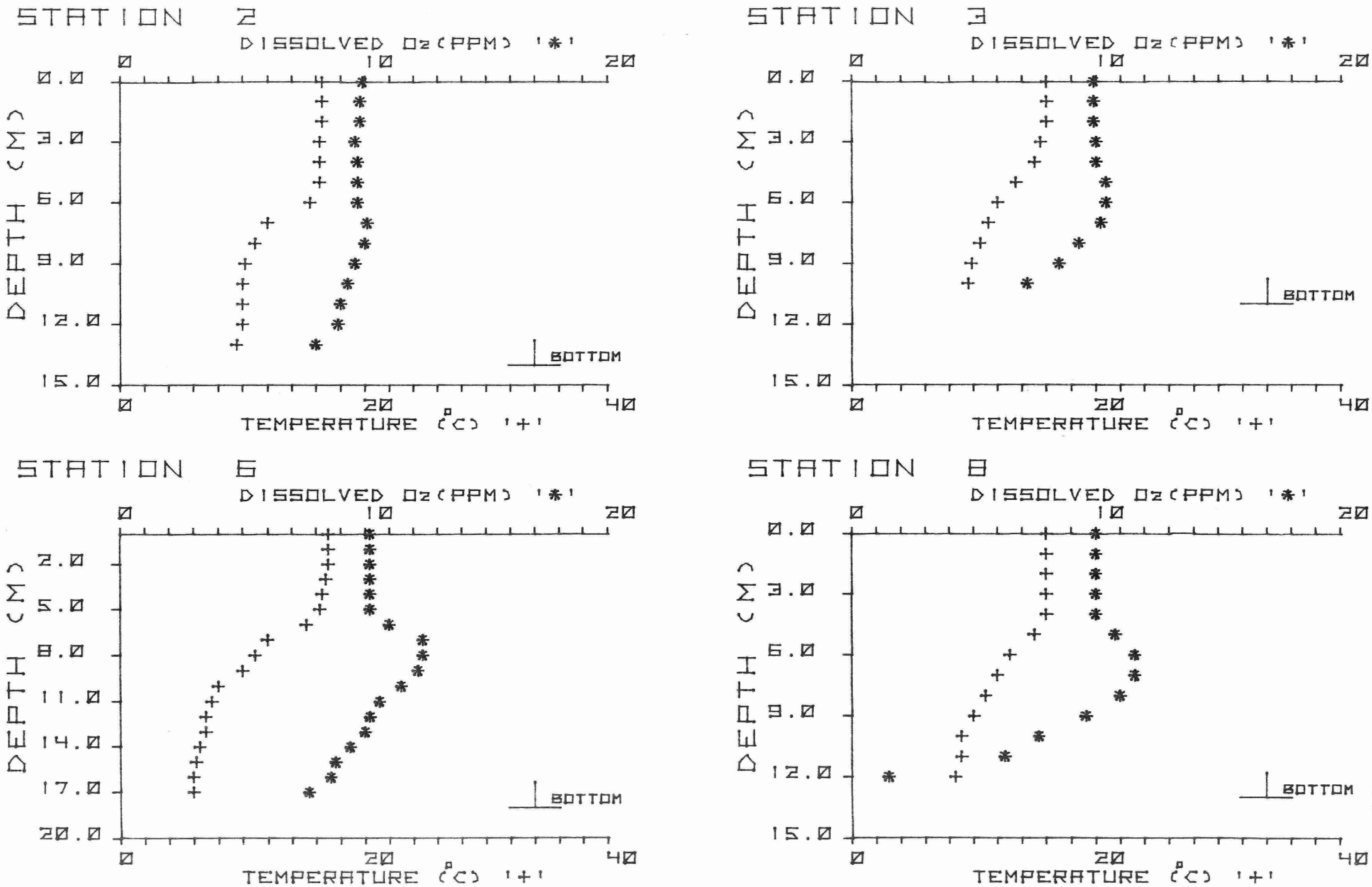
The distribution of dissolved oxygen from surface to bottom during periods of thermal stratification (partitioning of the water column due to differences in temperature and density) can be used as an indication of trophic status (degree of nutrient enrichment). A diagram showing the relationship between trophic status and vertical oxygen-temperature distributions is presented as Figure 5.

During the summer stratification period the vertical oxygen distribution in high quality oligotrophic (nutrient poor) lakes is termed orthograde which means that oxygen concentrations in the cold bottom waters are higher than in the warmer surface zone.

In poor quality eutrophic (nutrient rich) lakes, where recreational activities like swimming and boating may be made less pleasant due to turbid water, algae blooms and weed growths, vertical dissolved oxygen distributions are clinograde. Dissolved oxygen concentrations decline from surface to bottom due to the oxidation of organic matter settled on the bottom.

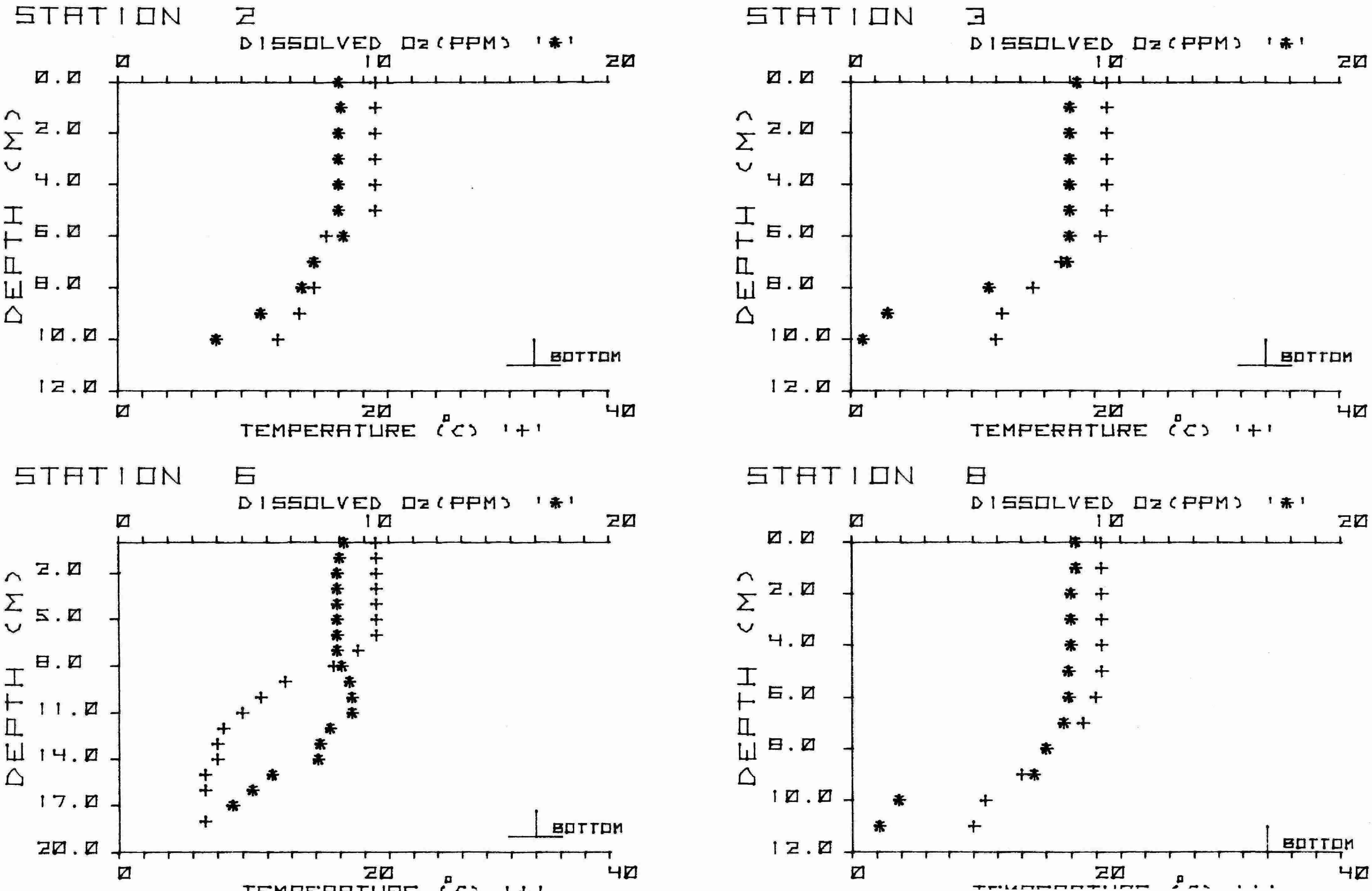
EAGLE LAKE

NORTHEASTERN REGION - M.O.E. JUNE 7 1978 **FIGURE 4a**



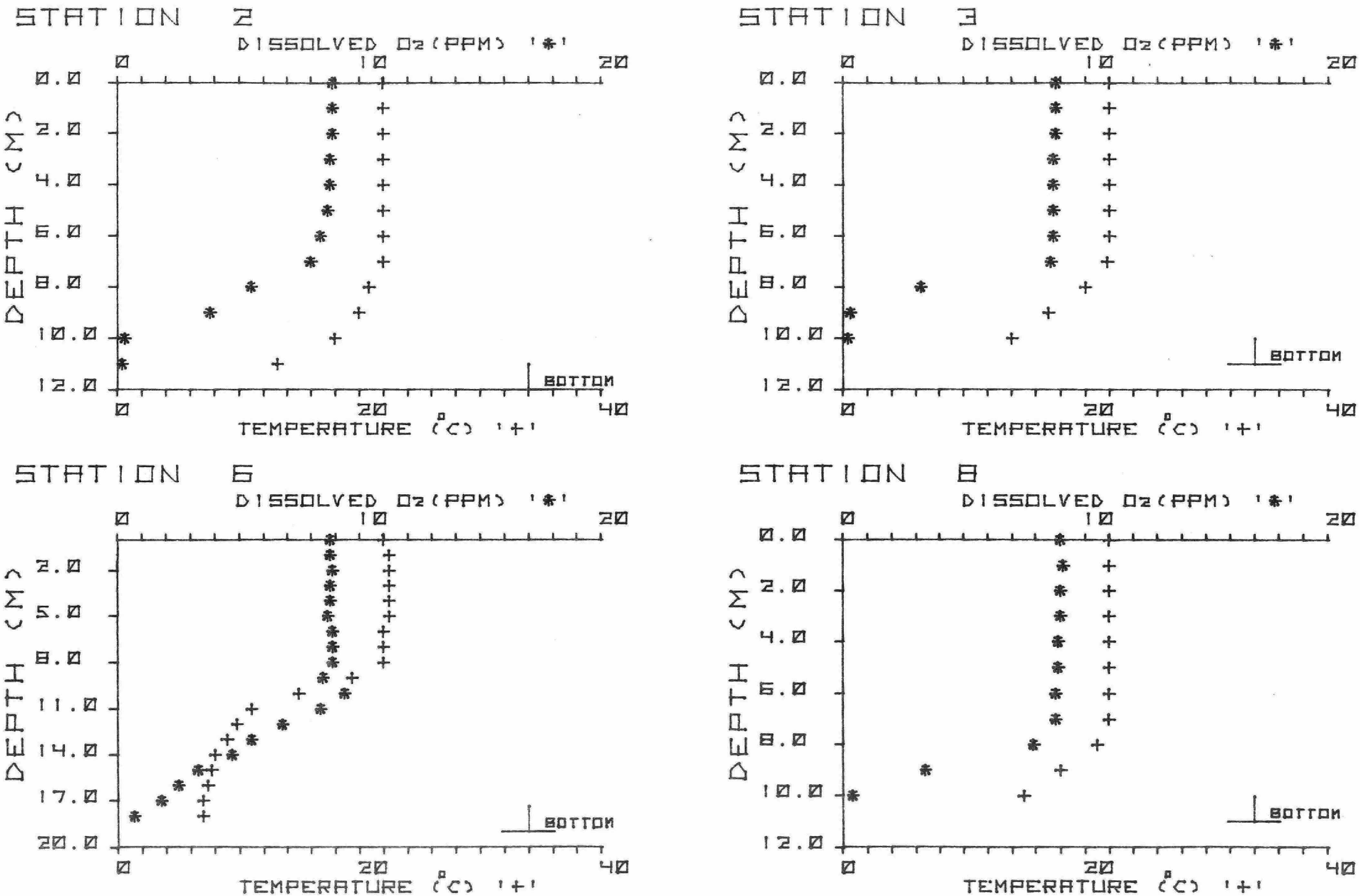
EAGLE LAKE

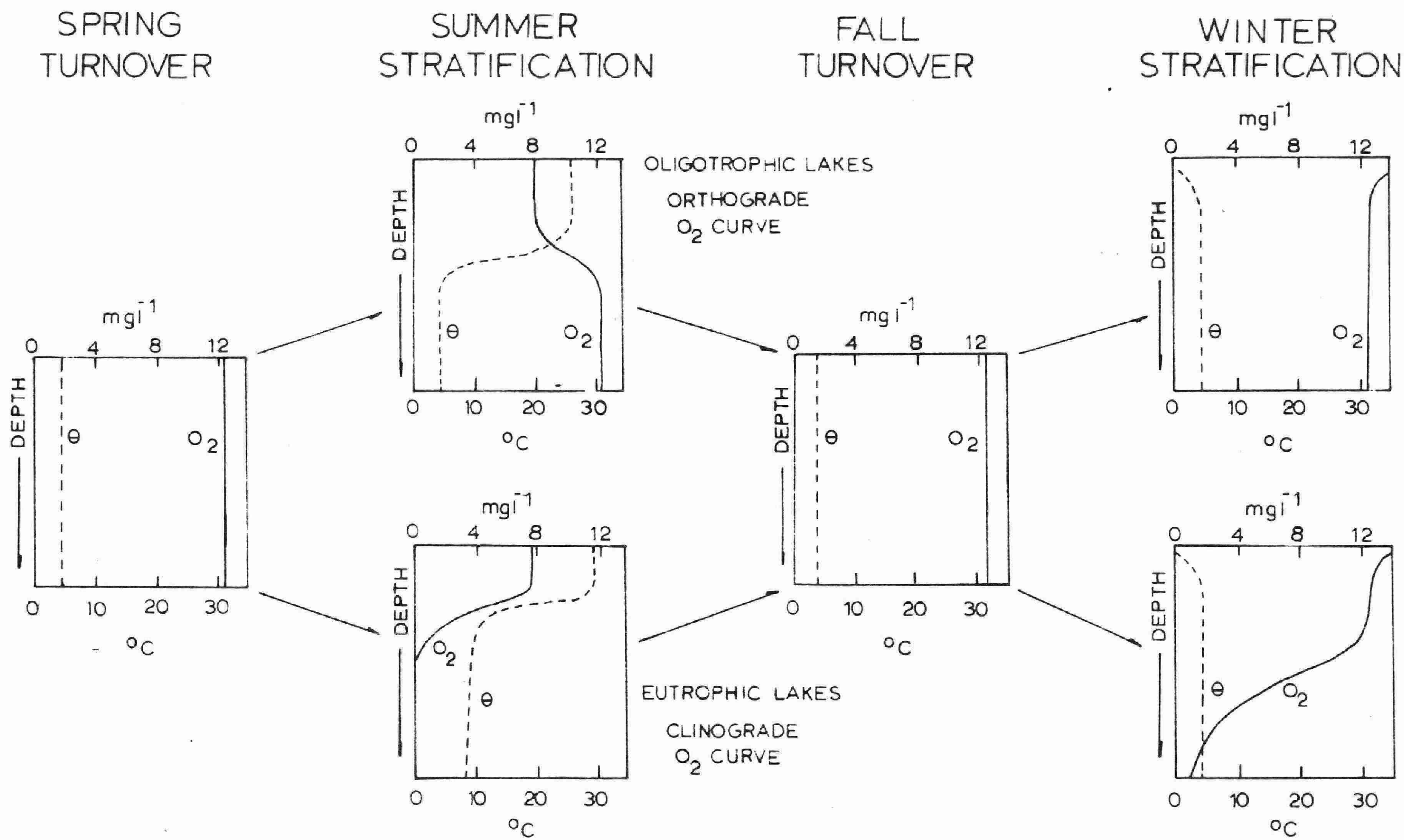
NORTHEASTERN REGION - M.O.E. JULY 11 1978 **FIGURE 4b**



EAGLE LAKE

NORTHEASTERN REGION - M.O.E.   AUG 23 1978   FIGURE 4c





IDEALIZED VERTICAL DISTRIBUTIONS OF OXYGEN CONCENTRATIONS (O_2) AND TEMPERATURE (θ) OF OLIGOTROPHIC (NUTRIENT POOR) AND EUTROPHIC (NUTRIENT ENRICHED) LAKES

FIGURE 5

FROM WETZEL, LIMNOLOGY

In extreme situations (Figure 5) oxygen levels below the warm surface layer may drop to zero, making the deep areas of the lake unsuitable for the support of aquatic life.

In mesotrophic (moderately enriched) lakes, where conditions between those described above may prevail, dissolved oxygen concentrations in the cold bottom waters may fall below the requirements of the organisms utilizing the particular habitat and may result in the stressing and eventual decline of the cold water organisms.

Ministry of the Environment dissolved oxygen objectives for cold water biota (lake trout) are temperature related and are stated below.

DISSOLVED OXYGEN CONCENTRATION COLD WATER BIOTA

Temperature ^{o}C	Oxygen mg/L
0	8
5	7
10	6
15	6
20	5
25	5

Eagle Lake is relatively shallow. The only deep basin (station 6, Figure 2) has a maximum depth of approximately 22 metres. In relation to other Precambrian Shield lakes, and lakes in general, this basin can only be classified as being moderately deep.

On June 7, thermal stratification was evident from the temperature profiles shown in Figure 4 (a). The separation of the warm surface water (17^{o}C) and cold bottom water

(6 - 10^{o}C) occurred at a depth of approximately 5.5 metres.

Even at this early stage of stratification, dissolved oxygen concentrations in the bottom water zone were observed to follow a declining pattern with depth. However, concentrations in the bottom waters still remained above the 6 mg/L cold water biota requirement.

By July 11, the thermocline (zone of rapid temperature decline) had sunk to a depth of 7 - 8 metres (Figure 4b). Surface water temperatures approached 21^{o}C while near the bottom, temperatures ranged from 7^{o}C at the deepest station to 12^{o}C at the shallower ones.

The less favourable clinograde oxygen distributions were apparent at each sampling location on July 11. Concentrations of dissolved oxygen remained at saturation levels (9 mg/L) in the well mixed surface waters and declined in the cold water zone of each sampling location. Oxygen concentrations fell below 6 mg/L at a depth of 9 m at Station 2, and 8 m at Station 3, 15 m at Station 6 and 9 m at Station 8.

Because the shallow nature of Stations 2, 3, and 8 facilitated warming of the water column above the temperature usually considered the upper favourable limit for cold water biota (12^{o}C), and because of unfavourable near-bottom oxygen concentrations at these stations, they were no longer suitable as cold water habitat by July 11. Station 6, the deepest basin was only marginally suitable.

By August 23, only Station 6 exhibited a classical thermal partitioning (Figure 4c). Stations 2, 3, and 8 showed a steady temperature decline below a depth of 8 metres and low

dissolved oxygen concentrations in the zone of temperature decline.

At Station 6, dissolved oxygen concentrations fell below 6 mg/L at a depth of 11 m revealing a reduction of 4 m of cold-water habitat over what existed in July.

Since lake turnover (mixing of the water column and replenishment of depleted oxygen) does not usually occur in this area of Central Ontario until late September or mid October, further reductions of dissolved oxygen could be expected in the cold water zone of Station 6. Stressing of cold water biota like lake trout in what appears to be their only suitable late summer habitat seems inevitable.

From the development of the oxygen profiles, the indications are that Eagle Lake is at, or is approaching a mesotrophic category. It seems to have limited capability to support a cold water fishery due to the physical constraints imposed by a relatively small summer hypolimnetic volume and the reduction of dissolved oxygen concentrations.

WATER CHEMISTRY EVALUATION

Results of chemical analyses for samples obtained in June, July and August are shown in Tables 2, 3, and 4. Data are included for samples taken one metre off the bottom of the deeper basins designated as Stations 2, 3, 6 and 8 in Figure 2. The northern half of the lake was represented by sampling stations 1, 2 and 3.

TABLE 2

CHEMICAL WATER QUALITY OF EAGLE LAKE

JUNE 7, 1978

PARAMETER	S B	E-1	E-2	E-3	E-4	E-5	E-6	E-7	E-8
Hardness	S	11	11	11	11	11	10	10	11
	B		11	11			11		11
Alkalinity	S	7	7	6	6	6	5	5	5
	B		7	7			6		6
pH	S	6.56	6.54	6.47	6.70	6.59	6.57	6.67	6.46
	B		6.34	6.17			6.05		6.02
Conductivity	S	37.5	36.0	36.5	35.5	35.5	35.5	35.5	36.0
	B		36.5	37.0			37		37.0
Total Phosphorus	S	.011	.008	.011	.006	.004	.007	.009	.009
	B		.023	.028			.014	.018	
Total Kjeldahl Nitrogen	S	.26	.26	.26	.25	.26	.23	.26	.27
	B		.41	.47			.34		.43
Ammonia	S	.016	.016	.036	.014	.010	.014	.026	.028
	B		.096	.094			.078		.098
Nitrite	S	.003	.004	.002	.002	.002	.002	.002	.002
	B		.002	.002			.002		.001
Nitrate	S	.055	.065	.065	.030	.025	.030	.010	.030
	B		.080	.085			.100		.065

TABLE 2 (Continued)

CHEMICAL WATER QUALITY OF EAGLE LAKE

JUNE 7, 1978

PARAMETER	S B	E-1	E-2	E-3	E-4	E-5	E-6	E-7	E-8
Sulfate	S	8.5	8.5	8.5	8.5	8.5	8.0	8.0	8.0
	B		8.0	7.5			8.0		8.0
Chloride	S	1.2	1.2	1.2	1.7	1.7	1.7	1.7	1.7
	B		1.1	1.2			1.7		1.7
Iron	S	.07	.04	.04	.02	.02	.02	.03	.02
	B		.10	.15			.03		.06
Colour	S	13	11	11	4	6	7	4	7
	B		15	16			9		11

S - Surface
B - Bottom

* All concentrations in mg/L except pH, conductivity (umhos/cm) and colour (Hazen units).

TABLE 3

CHEMICAL WATER QUALITY OF EAGLE LAKE

JULY 11, 1978

PARAMETER	S B	E-1	E-2	E-3	E-4	E-5	E-6	E-7	E-8
Hardness	S	11	11	12	11	11	11	10	11
	B		11	11			11		12
Alkalinity	S	6	7	7	6	6	6	6	6
	B		7	9			6		8
pH	S	6.85	6.68	6.68	6.7	6.8	6.66	6.77	6.63
	B		6.28	6.22			6.15		6.07
Conductivity	S	35.5	35.5	35.5	35.0	36.0	35.5	37.5	36.5
	B		38.0	38.5			37.5		40.0
Total Phosphorus	S	.005	.009	.008	.006	.005	.005	.007	.009
	B		.010	.016			.006		.024
Total Kjeldahl Nitrogen	S	.26	.26	.29	.24	.23	.23	.28	.24
	B		.35	.49			.33		.66
Ammonia	S	.004	.004	.014	.004	.004	.006	.006	.004
	B		.090	.168			.118		.312
Nitrite	S	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001
	B		.001	.002			.002		.002
Nitrate	S	<.005	<.005	<.005	<.005	<.005	<.005	<.005	<.005
	B		.040	.038			.113		.033

TABLE 3 (Continued)

CHEMICAL WATER QUALITY OF EAGLE LAKE

JULY 11, 1978

PARAMETER	S B	E-1	E-2	E-3	E-4	E-5	E-6	E-7	E-8
Organic Carbon	S B	3.6	3.2 3.2	3.2 3.2	2.9	2.9	2.9 2.4	3.3	3.2 2.8
Inorganic Carbon	S B	0.8	1.0 2.6	1.0 3.8	0.6	0.8	0.8 2.2	0.8	0.8 4.0
Sulfate	S B	8.5	8.0 8.0	8.0 7.5	8.0	8.0	8.0 8.0	8.0	8.0 8.0
Chloride	S B	1.2	1.1 1.2	1.1 1.2	1.6	1.7	1.7 1.7	1.7	1.7 1.7
Iron	S B	.04	.08 .22	.07 .62	.03	.03	.02 .10	.05	.04 .35
Colour	S B	8	1 10	1 22	1	0	0 4	0	2 11

S - Surface
B - Bottom

* All concentrations in mg/L except pH, conductivity (umhos/cm) and colour (Hazen units).

TABLE 4

CHEMICAL WATER QUALITY OF EAGLE LAKE

AUGUST 23, 1978

PARAMETER	S B	E-1	E-2	E-3	E-4	E-5	E-6	E-7	E-8
Hardness	S	12	14	11	11	11	11	11	11
	B		13	12			11		11
Alkalinity	S	7	8	7	7	6	6	7	7
	B		9	8			6		6
pH	S	6.94	6.78	6.74	6.73	6.96	6.78	6.8	6.61
	B		6.36	6.86			6.02		6.82
Conductivity	S	37.5	37.5	37.5	37.0	36.5	37.0	36.5	36.5
	B		38.5	37.0			36.5		35.5
Total Phosphorus	S	.005	.008	.007	.004	.004	.004	.008	.006
	B		.019	.006			.008		.004
Total Kjeldahl Nitrogen	S	.24	.27	.27	.25	.24	.24	.26	.24
	B		.36	.25			.26		.23
Ammonia	S	.014	.022	.016	.010	.008	.014	.024	.016
	B		.076	.018			.052		.016
Nitrite	S	.001	.001	.001	.001	.001	.001	.001	.001
	B		.002	.001			.002		.001
Nitrate	S	<.005	<.005	<.005	<.005	<.005	<.005	<.005	<.005
	B		<.005	.115			.175		.005

TABLE 4 (Continued)

CHEMICAL WATER QUALITY OF EAGLE LAKE

AUGUST 23, 1978

PARAMETER	S B	E-1	E-2	E-3	E-4	E-5	E-6	E-7	E-8
Organic	S	3.5	3.4	3.2	2.8	2.8	2.7	2.8	2.6
Carbon	B		2.9	3.3			2.2		2.8
Inorganic	S	1.0	1.0	1.4	0.6	0.6	0.4	0.6	1.0
Carbon	B		3.2	1.0			2.4		0.8
Sulfate	S	8.5	8.5	8.5	8.5	8.5	8.5	8.0	8.5
	B		7.5	8.5			8.5		8.5
Chloride	S	1.2	1.2	1.2	1.7	1.7	1.7	1.7	1.7
	B		1.2	1.2			1.7		1.7
Iron	S	.10	.14	.14	.08	.02	.02	.08	.04
	B		.30	.13			.16		.05
Colour	S	11	13	14	7	8	6	11	8
	B		24	10			17		5

S - Surface
B - Bottom

* All concentrations in mg/L except pH, conductivity (umhos/cm) and colour (Hazen units).

The differences in water chemistry between the northern and southern sections of the lake were very slight. The only point of differentiation appeared to be chlorides which were consistently 0.5 mg/L higher in the southern section.

Within the characterization parameter group, concentrations of hardness and its two principal component ions, calcium and magnesium remained relatively constant and uniformly distributed throughout the water column.

Conductivity values, which are an indication of the quantities of dissolved substances, remained low throughout the summer. At the deeper sampling stations, quantities of dissolved substances appeared to increase near the bottom in June and July but the changes were not considered to be significant.

Recent findings that acidic precipitation is widespread and prevelant in the Precambrian Shield region of Ontario accent the importance of determining a waterbody's natural acid buffering ability. This is done by measuring alkalinity. As shown in Tables 1 through 4, alkalinity improved over the sampling period from an average of 5 mg/L in May to 7 mg/L in August. The buffering capacity of Eagle Lake is low. Lakes with alkalinity values less than 10 mg/L are considered to be sensitive to acidic inputs. Depression of alkalinity in the spring is commonly associated with acidic spring runoff.

Ministry of the Environment objectives pertinent to recreational suitability and the protection of aquatic

life, state that pH should be maintained within a range of 6.5 to 8.5 units. Except for the initial survey in May when average pH was 6.2 units, the pH of surface waters was 6.5 or higher and improved through the summer.

The pH reduction in the bottom waters of Stations 2, 3, 6 and 8 during the summer is a commonly observed phenomenon resulting from the decomposition of settled organic matter.

Colour in natural surface waters is primarily associated with the presence of humic acids derived from the decomposition of plant material. Colour determinations which measure the intensity of the yellow-brown hue include the colour due to dissolved substances as well as the colour contributed by suspended matter. Most naturally coloured waters are harmless; however, a drinking water objective of 5 Hazen units is specified for aesthetic reasons. Determinations of colour from May through August indicate a very low colour coefficient in the surface waters with the northern half of the lake exhibiting slightly higher values.

Increases is water colour from settled organic matter and higher iron values were observed in the near-bottom samples from the deep stations.

Chloride and sulphate are two common anions the presence of which in high concentrations is often related to the influence of man. Chloride poses no direct health hazard but a salty taste may be noticed if concentrations exceed 250 mg/L. Urban runoff often contains high concentrations of chloride in the wintertime due to road salt application.

The concentrations of chloride found in Eagle Lake are considered to be low. The slightly higher concentrations detected in the southern basin (1.7 mg/L compared to 1.2 mg/L) may either be the product of road salt application or input from shoreline development.

Sulphate is a widely distributed ionic component in natural waters normally varying between 10 and 80 mg/L. It can also be added to a watershed through atmospheric fallout originating in the oxidation of sulphur dioxide from industrial sources.

Sulphate concentrations in Eagle Lake were very low averaging 8 mg/L.

The remaining characterization parameters investigated included organic carbon and iron.

Organic carbon is a measure of carbonaceous components and can be related to water colour. The concentrations of organic carbon found ranged from 2.3 to 3.6 mg/L and were considered to be low.

Iron is a component of hemoglobin and an essential element for all life forms. It is non-toxic at high levels but objectionable in domestic water supplies because of the colour and the bitter taste it imparts. Iron can also be released from the lake bottom during the bacterial decomposition of settled organic matter under anoxic (no oxygen) conditions. During periods of lake turnover, the iron may reach surface waters and lead to unpleasant odours and shoreline discolouration.

In Eagle Lake, problems with iron were not apparent. Surface water concentrations were well below the 0.30 mg/L criterion used for drinking water. Normal increases in iron concentrations were also detected in the bottom waters of the deep stations where low oxygen conditions were encountered.

NUTRIENT CHARACTERISTICS

Phosphorus is considered to be the main nutrient regulating primary biological activity (algae growth). In natural waters concentrations of phosphorus less than 0.010 mg/L are low and not problematic whereas concentrations higher than 0.020 mg/L may lead to problem algae growths.

In Eagle Lake, total phosphorus concentrations in the surface waters ranged from 0.004 to 0.011 mg/L and were in the low range. At the deeper sampling locations, increases in bottom water phosphorus from decomposition of settled materials were observed. However, the concentrations reached, (0.004 - 0.028 mg/L), appeared to have little potential to induce problem conditions.

In the normal course of decomposition of nitrogenous organic matter, nitrogen goes through the following changes: Total organic nitrogen is transformed through bacterial action to ammonia which is oxidized through the unstable nitrite form to nitrate. The nitrate form is readily available for uptake by plants.

Concentrations of the organic total Kjeldahl nitrogen form ranged from 0.23 to 0.29 mg/L in the surface waters. Such concentrations are considered to be moderately low.

Increases in total Kjeldahl nitrogen concentrations to moderately high levels (0.33 - 0.66 mg/L) in the bottom waters of the deep sampling stations were breakdown products of organic material (algae) settling on the bottom.

Ammonia can be directly toxic to aquatic life. It has been found that the un-ionized fraction of the total ammonia present is the toxic component and that the concentration of un-ionized ammonia should not exceed 0.02 mg/L.

The percentage of un-ionized ammonia in aqueous ammonia solution is a function of pH and temperature. Where pH values are high (8 units or more) and warm temperatures prevail (20^{o}C or more) total concentrations of ammonia in excess of 0.60 mg/L may be problematic.

Because ammonia concentrations as high as 0.60 mg/L are only rarely found even under anoxic (no oxygen) conditions where fish will not be found anyway, the low oxygen situation will usually set precedence over high ammonia values.

Deep-water ammonia concentrations ranged from 0.016 to 0.312 mg/L achieving their highest levels in July when low oxygen concentrations near the bottom of sampling stations 3 and 8 were not conducive for oxidation of decomposing nitrogenous material to the nitrate form. Under the slightly acidic and cool water conditions existing in the bottom waters of Eagle Lake, the ammonia concentrations encountered were not problematic.

Surface water concentrations of ammonia remained low throughout the summer.

Concentrations of the unstable intermediate, nitrite, were very low and never exceeded 0.004 mg/L.

The nitrate form of nitrogen followed the expected concentration and distribution pattern. Moderately low nitrate concentrations detected in May (0.095 - 0.135 mg/L) gave way to reduced surface concentrations in June (0.010 - 0.065 mg/L).

Once nitrogen uptake through primary biological activity (plant growth) in the euphotic zone peaked in the summer, nitrate concentrations in the surface waters became very low (less than 0.005 mg/L). At the bottom of the deeper sampling stations, nitrate concentrations generally declined from spring levels and remained in the moderately low range.

At the deepest sampling station (6), an increasing trend in nitrates was observed over the summer. This was primarily the result of oxidation of nitrogenous organic matter.

Overall, a build-up of nitrogen was observed in the deep waters of Eagle Lake. Total nitrogen concentrations (sum of Kjeldahl, nitrite, and nitrate) near the bottom (0.5 mg/L) were approximately double those found in the surface waters in June and July and only one third higher in August (0.36 mg/L) when warming to the bottom resulted in complete mixing at Stations 2 and 8.

Inorganic carbon is a measure of the carbon in the bicarbonate and other forms that is readily available to support biological productivity. Concentrations in surface and bottom waters remained in the low 0.6 - 4 mg/L range. Slight increases over surface water values were detected near the bottom of the deeper stations due to the contribution of respired carbon dioxide from decomposition of sedimented material.

INFLOWING STREAM WATER CHEMISTRY

Results of chemical analyses for those streams with sufficient flow of water to allow sampling are shown in Table 5. Samples were obtained July 11 and August 23 (Figure 2).

The significance of the chemical composition of the inflowing streams is discussed relative to the chemistry of the receiving waterbody.

Due to the observed low volumes of flow in each of the inflowing streams, the influence of these streams on lake water chemistry during the summer was minor.

The streams designated as ST-1 and ST-6 emptied to the northern half of the lake. Stream ST-1 functioned in an importing capacity with a higher content of dissolved substances than the receiving lake basin (conductivity 52 versus 36 umhos/cm). The increased dissolved solids load consisted of higher hardness, alkalinity, increased nutrient content, phosphorus (0.034 mg/L), nitrogen (0.77 mg/L), inorganic carbon (3.9 mg/L), more chloride (3.3 mg/L), iron (2.4 mg/L) and organic carbon (7.8 mg/L).

Because of the presence of organic carbon, iron and the almost stagnant condition of the stream, a high colour component was present (69 Hazen units). The pH in July and August (6.4 and 6.5) was lower than that of the northern section of the lake (6.9).

TABLE 5

EAGLE LAKE INFLOWING STREAM WATER CHEMISTRY 1978

PARAMETER	J A	ST-1	ST-2	ST-4	ST-5	ST-6
Hardness	J	16	9	16	17	
	A	19	9	17	18	13
Alkalinity	J	11	6	15	10	
	A	14	5	16	11	12
pH	J	6.37	6.22	6.93	6.44	
	A	6.52	6.51	6.76	6.59	6.44
Conductivity	J	46.5	28.5	45.5	53	
	A	58	29.5	44	59	38.5
Total	J	.042	.057	.108	.027	
Phosphorus	A	.026	.026	.080	.124	.076
Total Kjeldahl	J	.72	.59	1.03	.52	
Nitrogen	A	.50	.46	.86	.50	1.04
Ammonia	J	.110	.042	.356	.042	
	A	.122	.018	.162	.014	.150
Nitrite	J	.009	.005	.013	.006	
	A	.005	.004	.012	.007	.012
Nitrate	J	.176	.120	.412	.409	
	A	.135	.010	.355	.365	.050
Inorganic	J	3.4	1.0	3.2	2.8	
Carbon	A	4.4	0.2	4.0	2.0	3.8

TABLE 5 (Continued)

EAGLE LAKE INFLOWING STREAM WATER CHEMISTRY 1978

PARAMETER	J A	ST-1	ST-2	ST-4	ST-5	ST-6
Organic	J	10.2	7.2	11.6	8.2	
Carbon	A	5.4	7.0	13.2	15.2	17.3
Sulphate	J	11.5	8.5	9.5	10.5	
	A	9.0	7.5	7.0	10.0	9.5
Chloride	J	2.4	1.2	1.1	4.2	
	A	4.1	1.4	0.9	6.0	.8
Iron	J	2.9	.78	3.0	2.8	
	A	1.8	.57	2.4	1.8	3.1
Colour	J	46.5	28.5	45.5	53	
	A	92	70	106	151	228

J - July
A - August

* All results in mg/L except pH, conductivity (umhos/cm) and colour (Hazen units).

Although stream ST-6 was almost as dilute as the lake, (conductivity 38.5 umhos/cm) it was characterized by a deep yellow-brown colour (228 Hazen units). Because there was very little flow, high concentrations of accumulated organic compounds, (Kjeldahl nitrogen 1 mg/L, organic carbon 17.3 mg/L) and iron (3.1 mg/L) were detected. Total phosphorus (0.076 mg/L) and inorganic carbon (3.8 mg/L) were present in much higher quantities than the receiving basin while chloride levels were very low (0.8 mg/L).

Both streams inflowing to the northern basin of Eagle Lake were slightly acidic, exceeded the phosphorus guideline of 0.030 mg/L applied to flowing waters and conveyed a moderate load of the nutrients nitrogen and inorganic carbon. However, the very low flows and the large dilution available in the lake appeared to neutralize the input.

Stream stations 2, 3, 4 and 5 discharged to the eastern bay of the southern section of Eagle Lake (Figure 2). There was insufficient flow at Station ST-3 to obtain a sample.

Stream ST-2 which flowed to the bay represented by lake sampling station E7 was the most dilute with a conductivity of 29 umhos/cm. Concentrations of most parameters investigated except phosphorus, nitrogen, organic carbon, iron and colour were lower than those encountered in the lake.

Sampling stations ST-4 and ST-5 flowed to that area of Eagle Lake designated as lake sampling location E-6.

Conductivity values of 45 and 56 umhos/cm respectively, revealed that inflows ST-4 and 5 contained higher quantities of dissolved substances than did the lake (37 umhos/cm). Stream ST-4 was characterized by good alkalinity (15 mg/L), near neutral pH (6.9) and high concentrations of the nutrient elements, phosphorus (0.094 mg/L) and nitrogen (1.3 mg/L), of which approximately 30% was in the nitrate form readily available to plants. High colour (76 Hazen units) from stagnation, organic compounds and iron was also observed. Chloride levels of 1 mg/L were lower than the 1.7 mg/L concentration found in the lake.

Station ST-5 with the highest load of dissolved substances of all inflows contained an average chloride concentration of 5.1 mg/L. Elevated chloride concentrations are usually associated with runoff from winter road de-icing and summer dust control.

The inflow ST-5 was also highly coloured from the presence of organic carbon (12 mg/L) and iron (2.3 mg/L). In addition, elevated concentrations of phosphorus (0.076 mg/L) and nitrogen (0.9 mg/L) were detected in the slightly acidic stream (pH 6.5).

In conclusion, although the inflowing streams generally functioned as conveyors of dissolved substances, including nutrients, to Eagle Lake, they appeared to have little if any, visible impact on those areas of the lake where they they flowed in. The lack of local response of the lake to these inflows in terms of weed growth, algae blooms, significant deltaic sedimentation and impact on water chemistry, underlines the minimal influence of the inflows on the chemical quality of the receiving water during the summer.

HEAVY METAL CONTENT

Because of the relative proximity of the Sudbury smelting operations and the concern for metallic inputs from atmospheric fallout, the presence of potentially toxic heavy metals was investigated. Results of metal analyses for stations representing both the northern and southern basins are shown below:

	SAMPLING STATION			
PARAMETER	E-1	E-3	E-4	E-8
Copper	0.03	0.04	0.03	0.02
Nickel	Less than 0.02 at all stations			
Zinc	Less than 0.01 " " "			
Lead	Less than 0.03 " " "			
Cadmium	Less than 0.005 " " "			
Arsenic	Less than 0.001 " " "			

* All results in mg/L

Water which meets the water quality objectives for aquatic life and recreation will be suitable for most other uses such as drinking water and agriculture. Select Ontario metal objectives for the protection of aquatic life are summarized below:

Copper	0.005 mg/L	Lead	0.005 mg/L
Nickel	0.025 mg/L	Cadmium	0.0002 mg/L
Zinc	0.030 mg/L	*Arsenic	0.10 mg/L

* In drinking waters, arsenic concentrations in excess of .05 mg/L constitute grounds for rejection of the supply.

The above metal objectives are based on the total concentration of an unfiltered sample. It is recognized that metals may not be toxic in particulate or bound form and that it is possible for the total concentrations to exceed the objectives without damaging any aquatic life.

As shown in the heavy metal results table, the metal objectives appeared to be exceeded by the concentrations of copper present in the surface waters of Eagle Lake. The concentrations of the remaining metals were low and below the detection limits of the analytical methods used; although, in the cases of lead and cadmium, the objectives are set much lower than the detection limits.

The presence of surface water copper concentrations averaging 0.03 mg/L, six times higher than the objective of 0.005 mg/L,

requires additional comment. If these are true values, further investigation is warranted.

It is felt however, that the concentrations of copper may be aberrant and not worthy of concern for a number of reasons.

1) The detection limits and the sensitivity of the analytical apparatus is very much a function of environmental conditions (humidity, temperature) present in the room where the apparatus is situated.

2) The fact that the concentrations of all other metals analysed were low led to the suspicion that the reported copper values could be inaccurate.

3) Previous heavy metal sampling of Eagle Lake was undertaken during the Extensive Lake Monitoring Program associated with the Sudbury Environmental Study. The lake was sampled twice each during 1974 and 1975. Surface water copper concentrations ranged from less than 0.003 to 0.012 mg/L and averaged 0.006 mg/L. Concentrations detected in 1975 were lower than those found in 1974; therefore, no increasing trend was apparent.

4) On March 15, 1979, though-the-ice sampling of Eagle Lake in both the northern and southern basins revealed low copper concentrations of less than the detection limit of 0.010 mg/L.

CHLOROPHYLL a - SECCHI DISC

Historical data and a lake classification system based on the average summertime chlorophyll concentrations have been combined to allow mean annual Secchi disc readings and chlorophyll a concentrations to be grouped into ranges representing 4 degrees of water quality.

LEVEL 1 Chlorophyll a concentrations 0-2 ug/L, excellent water quality

LEVEL 2 Chlorophyll a concentrations 2-5 ug/L, good water quality

LEVEL 3 Chlorophyll a concentrations 5-10 ug/L, fair water quality

LEVEL 4 Chlorophyll a concentrations above 10 ug/L, poor water quality

Analytical chlorophyll a data and average Secchi disc readings are plotted on a graph displaying the ranges of Secchi disc visibility and chlorophyll a associated with specific levels of water quality.

(S.D.) SECCHI DISC (m) AND CHLOROPHYLL a (ug/L)
DATA COLLECTED FROM EAGLE LAKE IN 1978

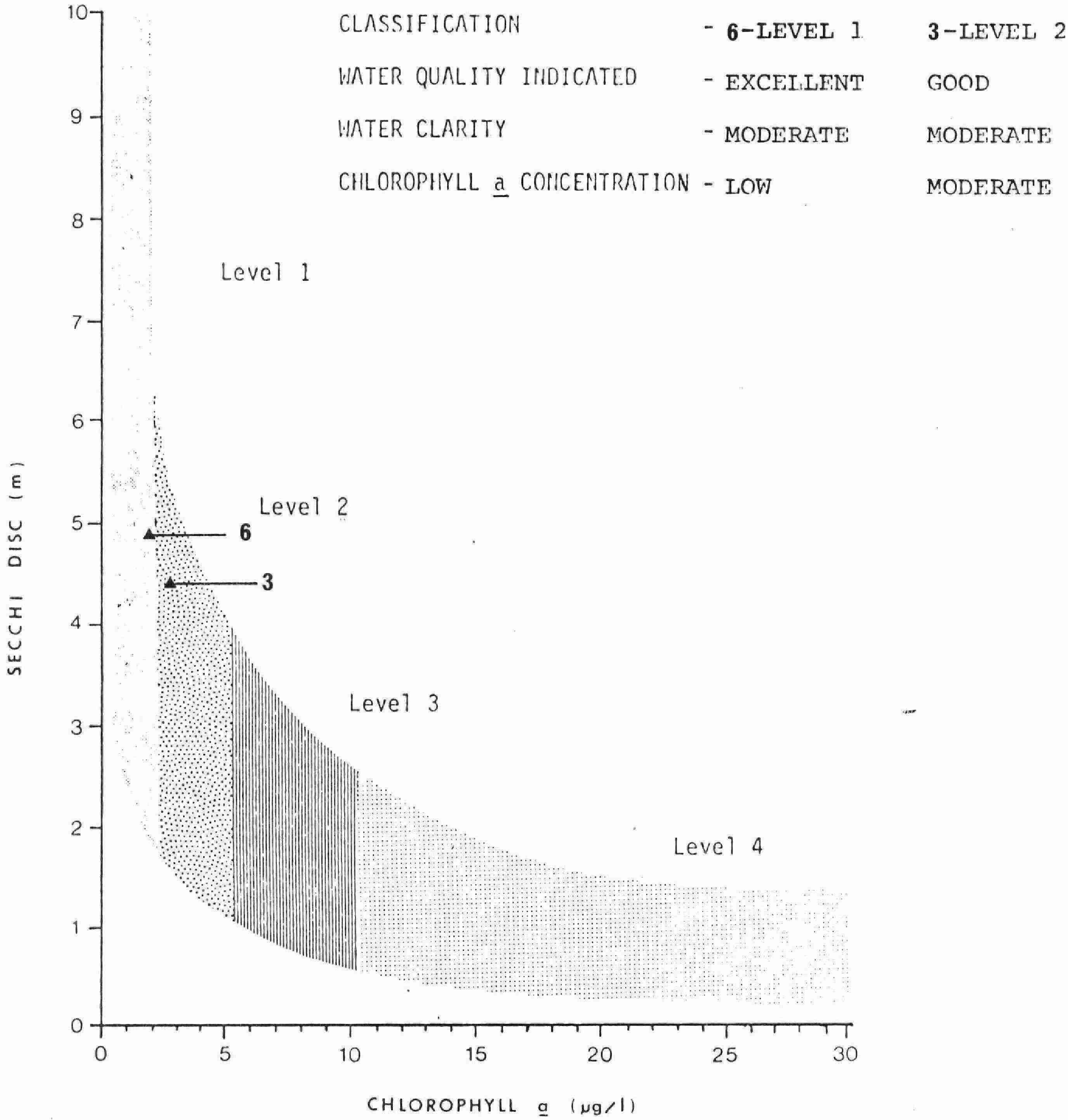
DATE	STATION 6		STATION 3	
	S.D.	Chloro. a	S.D.	Chloro. a
May 28	3.5	1.4	4.5	2.1
June 4	4.5	2.3	6.0	1.8
7	5.0	2.3	5.0	2.2
11	4.0	1.5	4.0	1.7
18	3.25	2.7	4.5	3.3
25	4.0	2.0	4.5	3.3
July 3	5.0	1.8	3.5	1.9
9	6.0	2.2	4.0	2.4
11	4.5	1.6	4.5	2.3
16	4.75	1.4	4.0	1.7
23	5.0	2.1	3.5	2.7
30	6.5	2.6	5.0	3.6
Aug. 6	5.5	1.8	4.5	2.4
11	5.0	1.7	3.5	2.3
13	5.25	1.2	5.5	2.1
23	6.5	1.2	5.5	1.9
27	5.0	1.8	4.0	3.3
Sept. 4	6.0	2.1	5.0	2.2
10	5.0	2.1	4.25	3.3
24	4.0	2.2	3.5	5.7

Secchi disc visibility from May to September varied within the moderate and excellent categories. At the same time chlorophyll a concentrations were low to moderate. One high reading of 5.7 ug/L was recorded at Station 2 on September 24.

SUMMARY OF MEAN VALUES FOR SECCHI DISC (m)
AND CHLOROPHYLL a (ug/L) COLLECTED FROM EAGLE LAKE

YEAR	STATION 6		STATION 3	
	S.D.	Chloro. a	S.D.	Chloro. a
1978	4.9	1.9	4.4	2.6

EAGLE LAKE, 1978



LAKE CLASSIFICATION BASED ON CHLOROPHYLL a SECCHI DISC RELATIONSHIP

KEY: Secchi Disc Visibility(m)		Chlorophyll a Concentration(ug/l)	
- 5 +	excellent	- 0 - 2	low
- 2.5 - 5	moderate	- 2 - 5	moderate
- 1 - 2.5	low	- 5 - 10	high
- 0 - 1	poor	- 10 +	excessive

Mean Secchi disc and chlorophyll a values plotted on the accompanying graph show that Station 6, the southern half of Eagle Lake is classified within the Level 1 or excellent category of water quality on the basis of primary biological activity while the northern section falls within the Level 2 or good class with a tendency toward Level 1.

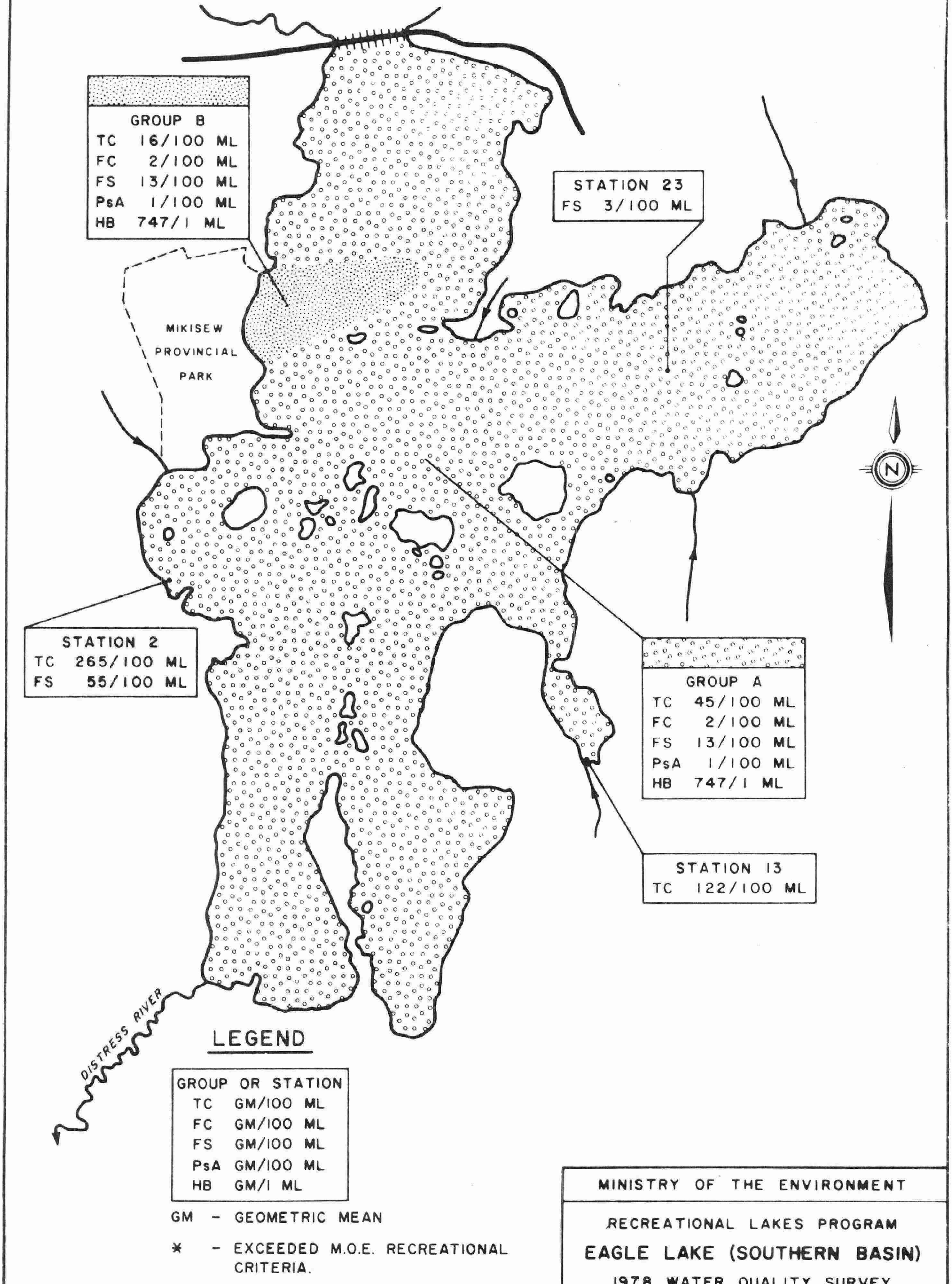
MICROBIOLOGY

The microbiological water quality of Eagle Lake during the August 1978 survey was generally good and, with few exceptions, was within the Ministry of the Environment Microbiology Criteria for Total Body Contact Recreational Use. According to the criteria, "where ingestion is probable, recreational waters can be considered impaired when the total coliform (TC), fecal coliform (FC) and/or enterococcus (fecal streptococcus, FS) geometric mean density exceeds 1000, 100 and/or 20 per 100 mL respectively, in a series of at least ten samples per month including samples collected during weekend periods".

Southern Basin

The densities of fecal pollution indicator bacteria were generally low at a majority of the stations in the southern basin of the lake. The geometric means (GM) for various parameters were 45 TC, 2 FC, 13 FS and 1 *P. aeruginosa* per 100 mL (Group A, Figure 7). Although most of the stations located on the western part of the southern basin also showed bacterial populations similar to those for Group A, a midlake (Station 25) and a shoreline (Station 30) location had low (16/100 mL) TC densities (Group B, Figure 7). Furthermore, another midlake (Station 23) recorded the lowest (3/100 mL) FS densities.

FIGURE 7 - DISTRIBUTION OF BACTERIA IN THE SOUTHERN BASIN OF EAGLE LAKE (AUGUST 17 TO 20)



MINISTRY OF THE ENVIRONMENT	
RECREATIONAL LAKES PROGRAM EAGLE LAKE (SOUTHERN BASIN) 1978 WATER QUALITY SURVEY	
SCALE: AS SHOWN	
DRAWN BY: ART. S.	DATE: MARCH, 1979
CHECKED BY:	DRAWING Nº: 8662

The highest levels of TC (265/100 mL) and FS (55/100 mL) were observed at Station 2, located on the southwest shore near a cottaged area. The relative concentrations of FC and FS indicated that contamination at this site probably originated from non-human sources in the surface runoffs.

In general, inflows usually have higher bacterial populations that the rest of the lake since they transport material (including human and animal wastes) from the surrounding land into the lake. At Station 13 (an inflow station), the bacterial densities were generally similar to those of Group A with the exception of higher TC levels (122/100 mL).

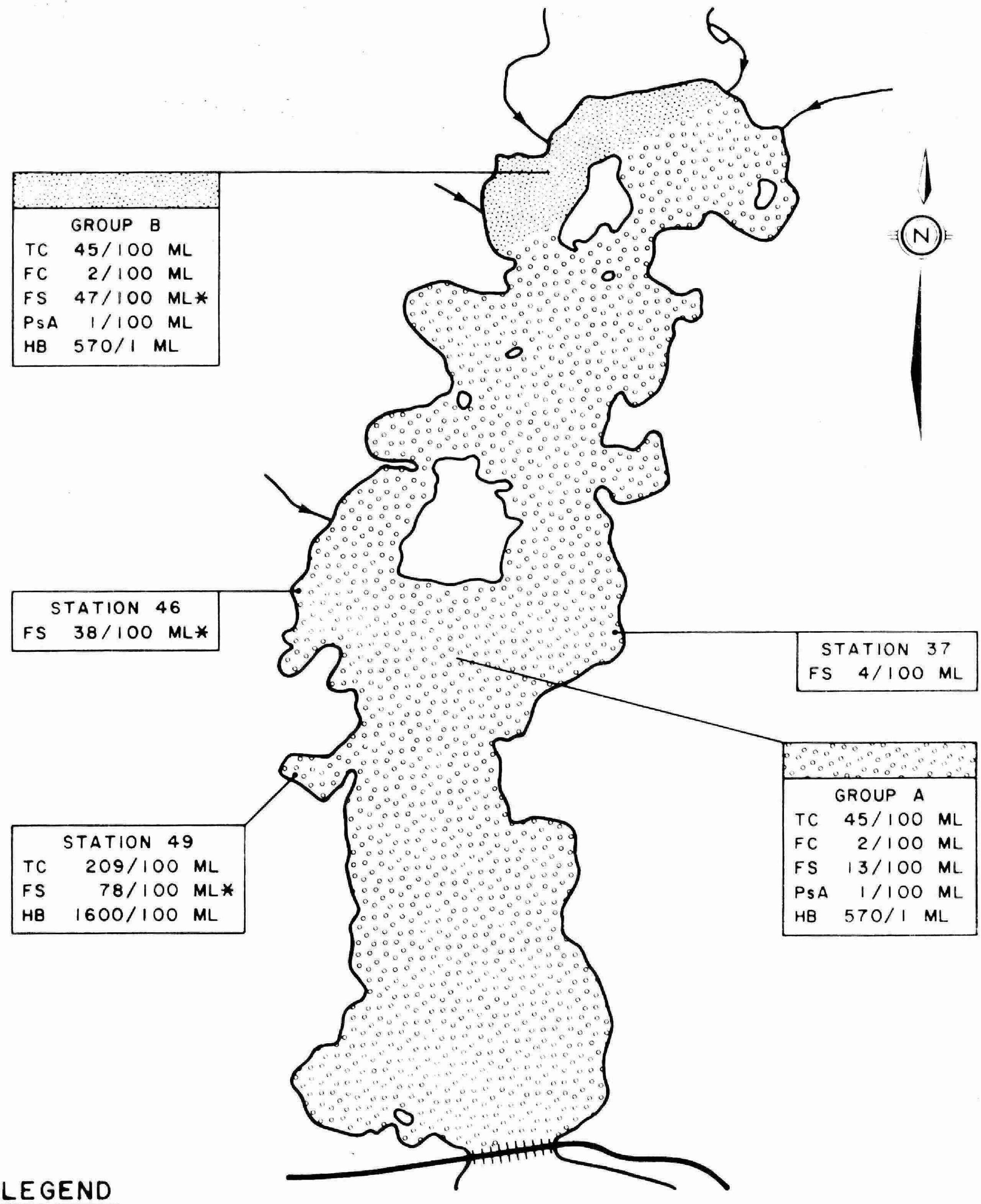
The populations of heterotrophic bacteria ranged from 341 to 1600/mL, with a GM of 747/mL (Figure 7). *Candida albicans* was not detected in water samples collected from three bathing beach locations (Stations 6, 30 and 31).

Northern Basin

The northern basin of Eagle Lake also showed low bacterial populations and, at most of the stations, densities of indicators were similar to those observed in the southern basin. The GM bacterial concentrations in the northern basin were 45 TC, 2 FC, 13 FS and 1 *P. aeruginosa* per 100 mL (Group A, Figure 8).

At the three inflowing stream locations (Stations 41, 42 and 43), high FS levels (47/100 mL) were observed (Group B, Figure 8). However, the TC, FC and *P. aeruginosa* densities at these stations were not significantly different from those of Group A.

FIGURE 8 - DISTRIBUTION OF BACTERIA IN THE NORTHERN BASIN OF EAGLE LAKE (AUGUST 20 TO 24)



LEGEND

GROUP OR STATION	
TC	GM/100 ML
FC	GM/100 ML
FS	GM/100 ML
PsA	GM/100 ML
HB	GM/1 ML

GM - GEOMETRIC MEAN

* - EXCEEDED M.O.E. RECREATIONAL CRITERIA.

0 5 1 KILOMETRES

MINISTRY OF THE ENVIRONMENT

RECREATIONAL LAKES PROGRAM

EAGLE LAKE (NORTHERN BASIN)

1978 WATER QUALITY SURVEY

SCALE: AS SHOWN	
DRAWN BY: ART S.	DATE MARCH, 1979
CHECKED BY	DRAWING Nº 8663

In Figure 8, the highest densities of TC (209/100 mL) and FS (78/100 mL) were obtained at Station 49, situated adjacent to a cottaged area on the west shore. The lowest FS concentrations were recorded at Station 37, located beside a cottage on the east shore. The relative populations of FC and FS at the inflows and cottaged locations suggested that the pollution was mainly of non-human source and probably originated in rural runoffs.

In the northern basin, the densities of heterotrophic bacteria were slightly lower than those observed in the southern basin of the lake. The HB levels at most stations varied between 408 to 810/mL with a GM of 570/mL (Figure 8). The highest HB concentrations (1600/mL) were observed at Station 49, situated near a cottage.

Water samples from the northern basin stations were not analyzed for the presence of C. albicans.

In summary, the northern and southern basins of Eagle Lake appeared to have relatively similar microbiological water quality which was generally good throughout the eight-day survey period as determined by low levels of fecal pollution indicator and heterotrophic bacteria. However, there were localized areas of bacteriological water quality degradation at some inflowing stream locations (Stations 13, 41, 42 and 43) and a few cottaged areas (Stations 2, 46 and 49). Bacterial concentrations, especially those of total coliforms and fecal streptococci, were higher in these areas than the rest of the lake. In addition, at these sites, the FS densities exceeded the M.O.E. Water Quality Criteria for Recreational Use. However, these were the only

instances where criteria violation occurred and the data indicated that the pollution in these localized areas was of non-human type and mainly originated from nonpoint sources.

Overall, the effect of existing development on microbiological water quality of Eagle Lake was minimal as the bacterial levels were not appreciably greater than those found in an undeveloped reference lake (Jerry Lake) in Central Ontario (M.O.E. 1973).

EAGLE LAKE PHOSPHORUS BUDGET

In the Northeastern Region of the Ministry of the Environment, a phosphorus budget approach is being used as an indication of water quality and as a prediction of water quality changes likely to occur following the development of shoreline housing units.

The rationale and input parameters used in the calculation of the phosphorus budget and the projection of the effects of additional shoreline development are shown in the Appendix.

It has been found (Dillon, 1974) that the trophic status (degree of nutrient enrichment) of lakes can be related to the amount of phosphorus present at spring turnover when the water is completely mixed.

General catagories or levels of water quality based on the quantity of total phosphorus present in the spring have been identified.

NOTE: Concentrations of phosphorus are reported as mg/m^3. This is equivalent to ug/L or parts per billion.

Level 1 (Excellent)

Springtime phosphorus concentrations between 0 and 9.9 mg/m^3. Such lakes are primarily suited for body contact recreation because of extremely clear water and low order of biological productivity. In deep lakes, dissolved oxygen concentrations in hypolimnetic (bottom) waters will remain favourable for the support of cold water fish species like lake trout.

Level 2 (Good)

Springtime phosphorus concentrations between 10 and 18.5 mg/m^3. Lakes in this category are suitable for water-based recreation but the preservation of cold water fisheries is not guaranteed. Level 2 lakes are less clear with moderate primary biological activity.

Level 3 (Fair)

Springtime phosphorus concentrations between 18.5 and 29.9 mg/m^3. Level 3 lakes are characterized by reduced suitability for body contact aquatic recreation because of high concentrations of suspended algae and associated nuisances like odours and turbid water. Oxygen depletion in deep basins will be common and there is danger of winterkill of fish in shallow lakes.

Level 4 (Poor)

Springtime phosphorus concentrations above 30 mg/m^3. Such lakes are suitable only for warm water fisheries and there is considerable danger of winterkill of fish. Other recreational uses like swimming, boating and water skiing are extremely unpleasant.

The spring phosphorus concentrations of Eagle Lake have been determined on a number of occasions. Data gathered by the Ministry of Natural Resources in 1975 revealed a concentration of 13 mg/m^3 for the northern section and 7 mg/m^3 for the southern end.

Ministry of the Environment sampling crews detected average spring phosphorus concentrations of 9 and 6.5 mg/m^3 in the north and south ends that same year.

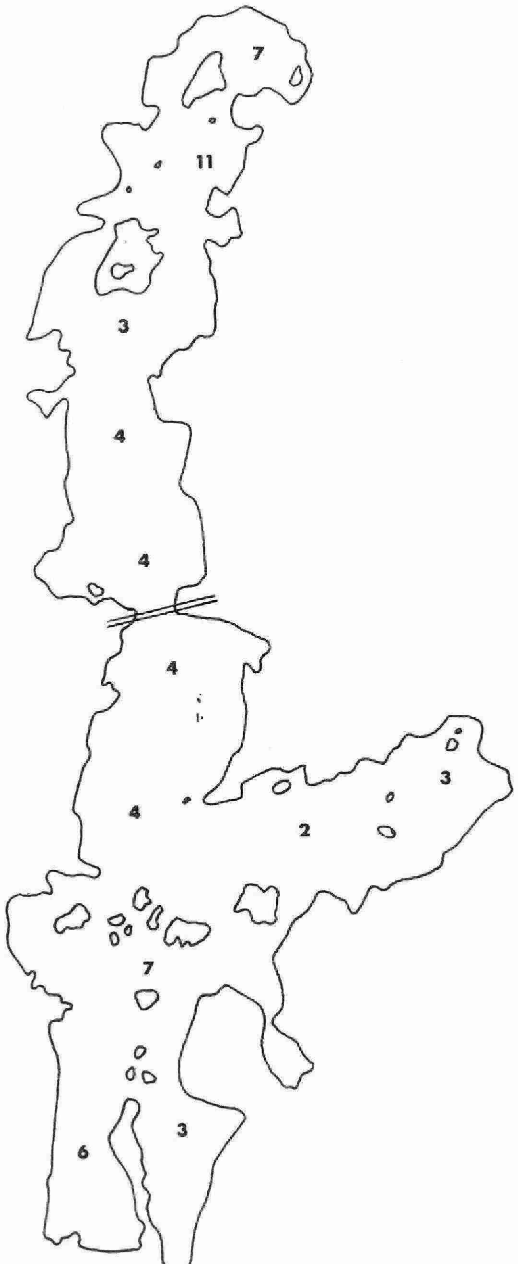
Prior to the expanded water chemistry survey in the summer of 1978 an intensive springtime phosphorus sample collection was undertaken. Results are summarized in Figure 9. The average phosphorus concentration for the northern sector of Eagle Lake was 5.8 mg/m^3 while in the southern half it was 4.1 mg/m^3. Such concentrations are very low and if taken at face value, indicate excellent water quality. Because of the variation among spring phosphorus determinations an alternate method of trophic status classification was required.

One of the conditions associated with a Level 1 classification is a low standing crop of algae. When expressed in terms of chlorophyll a, lakes in the Level 1 class are characterized by average summer chlorophyll a concentrations less than 2 ug/L.

The average chlorophyll a concentration is related to springtime phosphorus by the following equation:

$$\log_{10} [\text{Chl } a] = 1.45 \log_{10} [P] - 1.14.$$

Therefore, on the basis of the 1978 spring phosphorus values of 5.8 and 4.1 mg/m^3 for the north and south basins respectively, average chlorophyll a concentrations of 0.93 and 0.56 ug/L should have been detected. In reality, the average chlorophyll a concentration for the northern sector was 2.6 ug/L and 1.9 ug/L for the southern end. The spring phosphorus concentrations equivalent to the chlorophyll a values detected



Upper Eagle

Average Spring Phosphorus: 5.8 mg/m^3
Classification: Level 1
Predicted Summer Chlorophyll: 0.93 mg/m^3

Lower Eagle

Average Spring Phosphorus: 4.1 mg/m^3
Classification: Level 1
Predicted Summer Chlorophyll: 0.56 mg/m^3

Average Spring Secchi Disc Visibility: 4.4 m

EAGLE LAKE   MACHAR TWP.

LAT. 45.50 N   LONG. 79.30 W

Ministry of The Environment
Water Resources Assessment
N. E. Region

EAGLE LAKE

SPRINGTIME PHOSPHORUS

1978

Date: **MAY 1978**	Scale	Fig. No.
Prepared By: **JKG**	**1:50,000**	**9**

are 11.8 and 9.5 mg/m^3 for the north and south ends respectively.

Since water chemistry, morphometry, dissolved oxygen regime and primary biological productivity show a tendency toward moderately enriched or mesotrophic conditions and because a very good record of chlorophyll a concentrations was on hand it was concluded that the spring phosphorus values suggested by the chlorophyll a data were most indicative of existing conditions.

The northern section of Eagle Lake was classified in Level 2 while the southern section was within Level 1.

Because of the physical separation and apparent trophic status differences between the northern and southern sections of Eagle Lake, individual phosphorus budgets and responses to development were calculated for each section.

In the calculation of a phosphorus budget for Eagle Lake, two sources of phosphorus were considered:

1) the phosphorus originating within the drainage basin i.e. natural load from runoff and precipitation on the lake surface. A phosphorus land export factor of 5.5 $mg/m^2/yr$ was used due to the igneous character of the bedrock geology and forested terrain. A precipitation loading of 75 $mg/m^2/yr$ was assumed.

2) the estimated artificial phosphorus input from septic tank tile fields of existing cottages. On site cottage counts revealed the presence of 314 units along the

shoreline of Eagle Lake. There was an even split of 157 units per basin.

From the estimation of septic tank phosphorus inputs, it was assumed that all phosphorus present in human waste finds its way to the lake. This amounts to approximately 800 gms/yr/person. For this reason, estimates of the effect of additional development are maximum effect estimates.

Phosphorus budget and development capacity were computed on an Hewlett Packard 9825A system. Calculator outputs are shown in the Appendix.

Based on theoretical phosphorus supply estimates for the northern half of Eagle Lake, a springtime phosphorus concentration of 8.2 mg/m^3 was predicted. It does not compare favourably with the value of 11.8 mg/m^3 suggested by the chlorophyll *a* sampling program. Also the theoretical springtime phosphorus estimate of 7.1 mg/m^3 for the southern half does not compare well with the 9.5 mg/m^3 value predicted by chlorophyll program.

There are likely other sources of phosphorus to the lake which are not accounted for in the model. These may include geological availability, private sewage disposal systems, near-shore activities of land owners, and land use practices in the watershed; however, these are thought to be minor.

It is more likely that the large discrepancy in measured and predicted chlorophyll *a* values was due to the fact that the

predictive model was derived for deep lakes which did not go anoxic (low oxygen) near the bottom thereby regenerating phosphorus from the sediments.

When the thermocline descends to the bottom in shallow bodies of water like Eagle Lake by mid or late summer, the water column becomes mixed and regenerated phosphorus is released to support a higher than theoretically predicted amount of biological activity (chlorophyll a).

The 11.8 mg/m^3 value suggested by the chlorophyll a average was used as a base for the calculation of the development capacity in the north end of Eagle Lake.

A maximum of 579 cottages or 114 permanent dwellings could be added before water quality deterioration to Level 3 was predicted.

For the southern half of the lake, the 9.5 mg/m^3 spring phosphorus concentration suggested by the chlorophyll a average of 1.9 ug/L was used as the base for calculation of development capacity.

As shown in the printer output for the lower half of Eagle Lake, a change in classification to Level 2 can occur when 65 cottages or 12 permanent dwellings are added to the shoreline.

Since Ontario water quality objectives state that lakes with average phosphorus concentrations below 10 mg/m^3 be maintained within the Level 1 class, the further development of the shoreline of the southern half of Eagle Lake should be evaluated very carefully in consultation with the North Bay District Office of the Ministry of the Environment. Nutrient inputs from watershed activities like road building, lot clearing and fertilization of lawns should be kept minimal.

Because of the 5:1 ratio of phosphorus supply for permanent versus seasonal residences, it should be realized that conversion of each existing seasonal unit to a permanent residence will reduce the cottage development capacity by 5 units. In addition, the number of vacant lots presently existing has not been included in the calculation of the development capacity nor have development reserves been allocated to the vacant lots.

SUMMARY WATER QUALITY STATUS

The general chemical water quality of Eagle Lake was very good. Concentrations of most characterization parameters investigated were low in this dilute lake. A depressed acidic pH was detected in the spring but it recovered to near-neutral values during the summer. The buffering capacity (resistance to acidic input) was found to be low.

Although cloud-like growths of the green filamentous alga *Zygmema* were prevalent throughout the summer in numerous shallow, near-shore areas over the whole lake, the nutrient parameters phosphorus, nitrogen and inorganic carbon were

found to be in the low to moderately low range. The quantities of suspended algae detected through the cottagers "Self-Help" monitoring program reflected the nutrient concentrations. The northern half of the lake carried a moderate standing crop of algae while the southern half had a moderately low standing crop.

Water clarity throughout the summer was at the high end of the moderate visibility range.

Although the majority of inflowing streams functioned in an importing capacity with a higher content of dissolved substances than their receiving basins, the very low flows and the large dilution available in the lake appeared to neutralize the stream inputs.

Concentrations of heavy metals in Eagle Lake were low, except for copper which appeared to exceed the water quality objectives. Although it is suspected that the copper concentrations detected were aberrant, additional investigation may be warranted pending future water chemistry monitoring.

Because Eagle Lake is relatively shallow with only one deep basin (22m) located in the eastern arm of the southern half of the lake, thermal stratification (partitioning of the water column into layers of differing temperature) was presistent only in the deep basin.

A reduction of deep water oxygen concentrations to the extent that stress conditions for cold water biota may be inevitable was observed in the deep basin during the late summer period.

On the basis of water chemistry, algal productivity and dissolved oxygen profiles, Eagle Lake can be classified at the transition between oligotrophic and mesotrophic conditions. The tendency is toward the mesotrophic or moderately enriched category.

In general, the effect of existing development and recreational use on bacterial levels has not been significant as densities of bacteria in the water column were similar to those associated with undeveloped lakes.

The results of shoreline spot surveys generally indicated good microbiological water quality during the survey period. There were localized areas of bacteriological water quality impairment near some of the inflowing streams as well as in front of three cottages; however, the elevated total coliform and fecal streptococcus densities detected at these sites appeared to be of animal or stormwater origin. No input from human sources was detected.

A theoretical phosphorus budget and development capacity based on the ability of Eagle Lake to assimilate additional nutrient loading revealed that the primary biological activity present was significantly higher than theoretically expected.

On the basis of the measured biological activity the northern half of Eagle Lake was classified in the Level 2 or good category of water quality. The development capacity for the northern end was calculated as an additional 578 cottages or 114 permanent dwellings.

For the southern or lower half of Eagle Lake a Level 1 or excellent classification was determined. If a Level 1 order of water quality is to be maintained a maximum of 65 additional cottages or 12 permanent dwellings can be assimilated along the shoreline.

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APPENDIX

PHOSPHORUS BUDGET CALCULATIONS

A prime concern of the Ministry of the Environment is to maintain acceptable water quality levels in lakes subjected to shoreline and backlot development pressures.

Water quality deteriorates with increasing quantities of algae (suspended aquatic plants) because they decrease water clarity. Upon decay, algae deplete oxygen supplies needed to support fish populations.

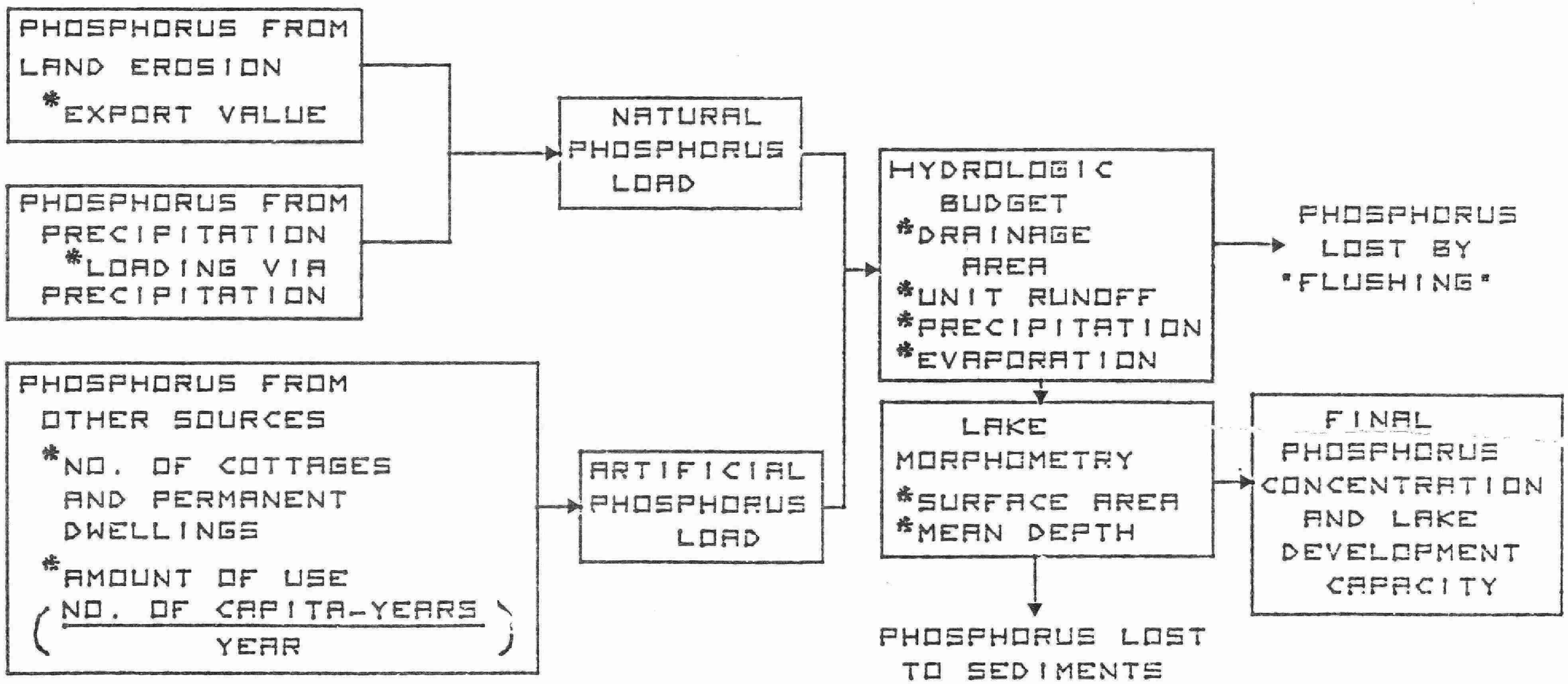
Phosphorus is the most important nutrient controlling the production of algae; so, the addition of phosphorus to a lake ultimately leads to a reduction of water quality.

Based on this concept, the average springtime phosphorus concentration can be used as an indication of the trophic status (degree of nutrient enrichment) of a lake.

A mathematical model (Dillon 1974) is used to provide a prediction of the average springtime phosphorus concentration in a lake by estimating natural and artificial (from shoreline development) inputs of phosphorus to the lake. The model is summarized in the accompanying flow diagram.

Natural inputs of phosphorus are due to the erosion and transport of phosphorus from the bedrock and surface soils, as well as dry fallout of dust containing phosphorus combined with phosphorus "washed" from the atmosphere via precipitation. Estimates of these inputs are shown in the key. The natural

DILLON'S MODEL



* INDICATES AN INPUT PARAMETER

phosphorus supply (Jn) is determined using the following equations:

$$\text{SUPPLY FROM LAND EXPORT} = \frac{E \times Ad}{10^6} = J_E \text{ (kg/yr)}$$

$$\text{SUPPLY VIA PRECIPITATION} = \frac{Lpr \times Ao}{10^6} = Jpr \text{ (kg/yr)}$$

$$Jn = J_E + Jpr$$

Where E is the land export value from the key, Ad is the lake's drainage area, Ao is the lake's surface area, and Lpr is the loading via precipitation (75 mg/m^2/yr).

Artificial phosphorus inputs originate primarily from human wastes, although detergents and fertilizers may contribute some phosphorus also. In order to calculate the artificial phosphorus inputs some assumptions must be made. On the average each person excretes about 0.8 kg of phosphorus per year, all of which is assumed to eventually enter the lake. In Ontario, an average of 3.9 people per household per year and 0.77 people per cottage per year are assumed. The artificial phosphorus supply (Ja) from houses and cottages can then be calculated as:

$$Ja = (N_d \times 3.9 + N_c \times 0.77) \times 0.8 \text{ (kg/yr)}$$

Where N_d is the number of houses and N_c is the number of cottages.

The total phosphorus supply (J_t) is simply the sum of the artificial and natural phosphorus supplies:

$$J_t = J_a + J_n$$

However, much of the phosphorus supply to the lake goes directly into lake sediments or is transported farther downstream of the lake's outflow. Thus the hydrologic budget and retention capacity of a lake must be estimated before arriving at a final effective phosphorus concentration.

To determine a lake's hydrologic budget the total outflow volume (Q) must be found. It is calculated as the sum of the input of water to the lake from runoff (Ad.r) and water input directly to the lake (Ao [Pr - Ev])

$$Q = Ad.r + Ao\,(Pr - Ev)$$

Where r is the unit runoff in m/yr., Pr is the mean annual precipitation in m/yr and Ev is the mean annual evaporation in m/yr.

The lake's flushing rate (F) is found as:

$$F = \frac{Q}{Ao \times \bar{Z}}$$

where Z is the lake's mean depth in m.

The retention of phosphorus by the lake is determined by the retention coefficient which is highly correlated with the areal water loading (Qs) where:

$$Q_s = Q/Ao$$

and the retention coefficient (R) is:

$$R = \frac{13.2}{13.2 + Qs}$$

If there is an upstream lake on the watershed it will retain some of the phosphorus from its drainage area. For each upstream lake the retention coefficient of the upstream lake is used to reduce the phosphorus supply to the inflow of the next lake.

The final predicted average springtime phosphorus concentration in the lake is calculated from:

$$[P] = \frac{(1 - R) \times J_t \times 10^6}{\bar{Z} \times F \times Ao}$$

To estimate the effect of any new development, the additional phosphorus supply is calculated and the new total phosphorus supply (J_t) is substituted back in the above equation to give another predicted springtime phosphorus concentration.

In the Northeastern Region, the new total phosphorus supply is calculated incrementally for two development types (full time dwellings and seasonal cottages). Calculations are performed on a Hewlett Packard 9825A programmable calculator and outputted in both printed and plotted form showing development capacity for the existing level of water quality.

The basis of Dillon's model is the theoretical springtime phosphorus concentration which is obtained by estimating natural and artificial phosphorus supplies. Because of uncertainty regarding the agreement of theoretical spring

phosphorus predictions with actual analytical determinations of spring phosphorus and the independence of the measured concentrations from possible "estimation" errors, the <u>actual measured springtime phosphorus concentration of a lake is preferred as the base for the determination of development capacity</u>. Theoretical concentrations are computed for comparison.

KEY

SYMBOL	MEANING	UNITS
Z	Mean depth of lake	m
Ao	Lake surface area	m^2
Ad**	Lake drainage area	m^2
Jn	Natural phosphorus supply	kg/yr
Ja	Artificial phosphorus supply	kg/yr
Jt	Total phosphorus supply	kg/yr
Nd	Number of houses	
Nc	Number of cottages	
Q	Total outflow volume	m^3/yr
r	Unit runoff	m/yr
Pr	Mean annual precipitation	m/yr
Ev	Mean annual evaporation	m/yr
F	Flushing rate	times/yr
Qs	Areal water load	m/yr
R	Retention coefficient	
Lpr	Phosphorus loading via precipitation	75 mg/m^2/yr
E*	Land export value derived from Table I	mg/m^2/yr

* TABLE I: AVERAGE EXPORT VALUES (mg/m^2/yr)

GEOLOGICAL CLASSIFICATION

LAND USE		IGNEOUS	SEDIMENTARY
Forest	Range	0.7 - 8.8	6.7 - 18.3
	Mean	5.5	10.3
Forest & Pasture	Range	5.9 - 16.0	11.1 - 37.0
	Mean	9.8	19.8

NOTE: When E is in the 5.5 mg/m^2/yr category, the export value should be calculated as follows:

$$E = 1.32 + 5.54\ Dd$$

Where Dd is the "drainage density" and

$$Dd = \frac{\text{(Length of Each Input Stream)}}{Ad} \quad (km^{-1})$$

** Drainage area of a lake is found by planimetry of watershed drawn on topographic maps.

ONTARIO MINISTRY OF THE ENVIRONMENT - NORTHEAST REGION

LAKE DEVELOPMENT CAPACITY - DILLON'S MODEL

LAKE: Eagle (Upper)

TWP.: Machar

DATE: Jan 20, 1979

SUMMARY: This lake is classified as a Level 2 lake. This means that the Spring Phosphorus Concentration ranges from 9.9 to 18.5 mg/cu.m. A maximum of 578 cottages or 114 permanent dwellings may be added to maintain a Level 2 classification.

The addition of 86 cottages or 17 permanent dwellings will result in a 1 mg/cu.m increase in the existing Spring Phosphorus Concentration.The full effect of any extra Phosphorus loading will be noticed after 1.3 years.

SUPPORTING DATA:

Lake Area(sq.m): 3391290
Drainage Area(sq.m): 15490392
Mean Depth(m): 5.70
Volume(cu.m): 19330353
Unit Runoff(m/yr):0.4800
Precipitation(m/yr): 0.81
Evaporation(m/yr): 0.51
Total Outflow Volume(cu.m): 8452775
Flushing Rate(Lake's vol./yr): 0.4373
Retention Coefficient(R):0.8412
Response Time(yr): 0.8 to 1.3

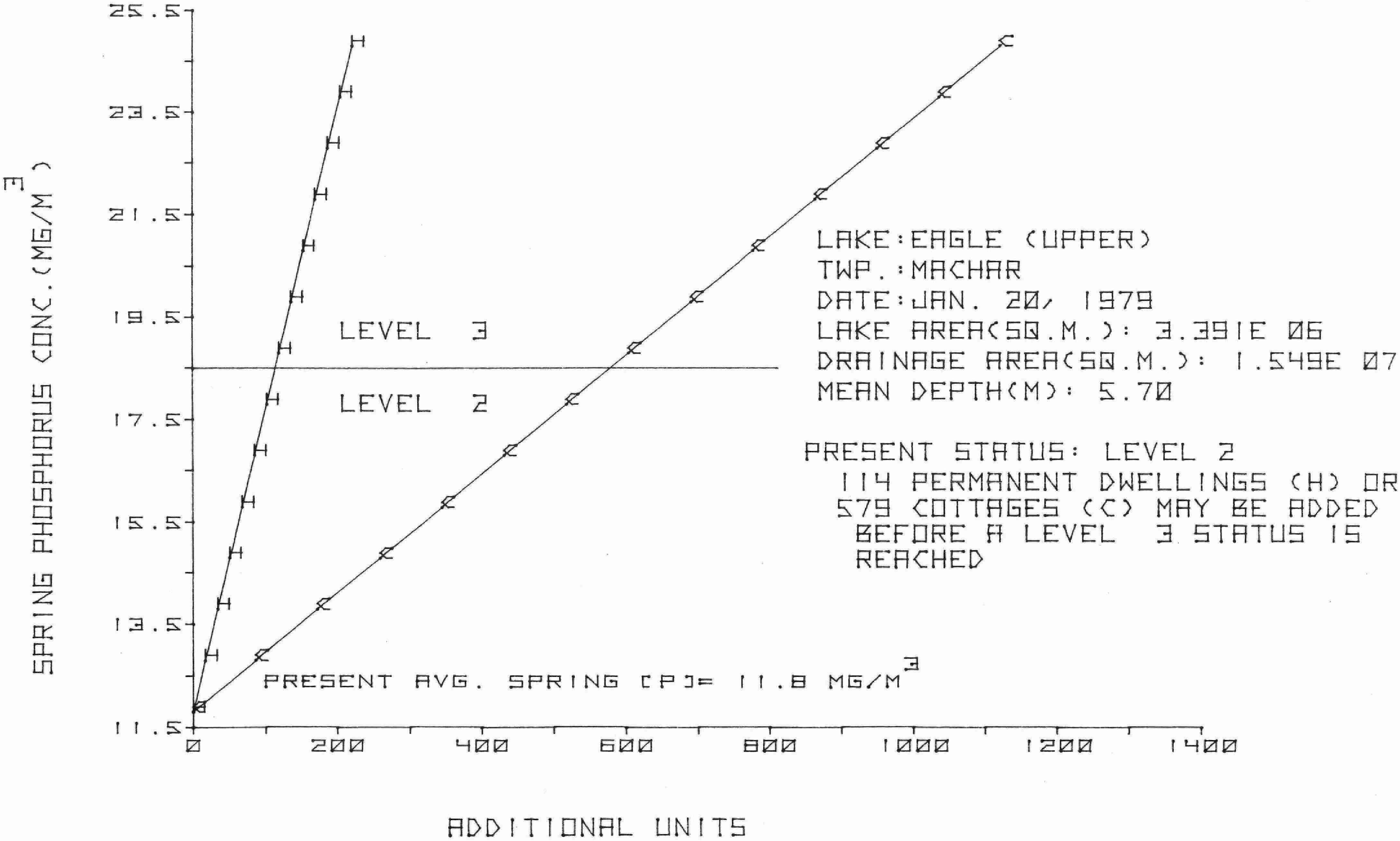
Actual Phosphorus Loading(mg/sq.m/yr): 185.17
Actual Phosphorus Supply(kg/yr): 627.97

MEASURED SPRING PHOSPHORUS CONCENTRATION(mg/cu.m): 11.8

Theoretical Phosphorus Loading(mg/sq.m/yr): 128.64
Theoretical Phosphorus Supply(kg/yr): 436.26

THEORETICAL SPRING PHOSPHORUS CONCENTRATION(mg/cu.m): 8.2

NORTHEAST REGION M.O.E.
LAKE DEVELOPMENT CAPACITY AFTER DILLON'S MODEL



ONTARIO MINISTRY OF THE ENVIRONMENT - NORTHEAST REGION

LAKE DEVELOPMENT CAPACITY - DILLON'S MODEL

LAKE: Eagle (Lower)

TWP.: Machar

DATE: Jan 26, 1979

SUMMARY: This lake is classified as a Level 1 lake. This means that the Spring Phosphorus Concentration ranges from 0.0 to 9.9 mg/cu.m. A maximum of 65 cottages or 12 permanent dwellings may be added to maintain a Level 1 classification.

The addition of 164 cottages or 32 permanent dwellings will result in a 1 mg/cu.m increase in the existing Spring Phosphorus Concentration.The full effect of any extra Phosphorus loading will be noticed after 1.4 years.

SUPPORTING DATA:

Lake Area(sq.m): 6328876
Drainage Area(sq.m): 30371151
Mean Depth(m): 6.50
Volume(cu.m): 41137694
Unit Runoff(m/yr):0.4800
Precipitation(m/yr): 0.81
Evaporation(m/yr): 0.51
Total Outflow Volume(cu.m): 17542803
Flushing Rate(Lake's vol./yr): 0.4264
Retention Coefficient(R):0.8265
Response Time(yr): 0.8 to 1.4

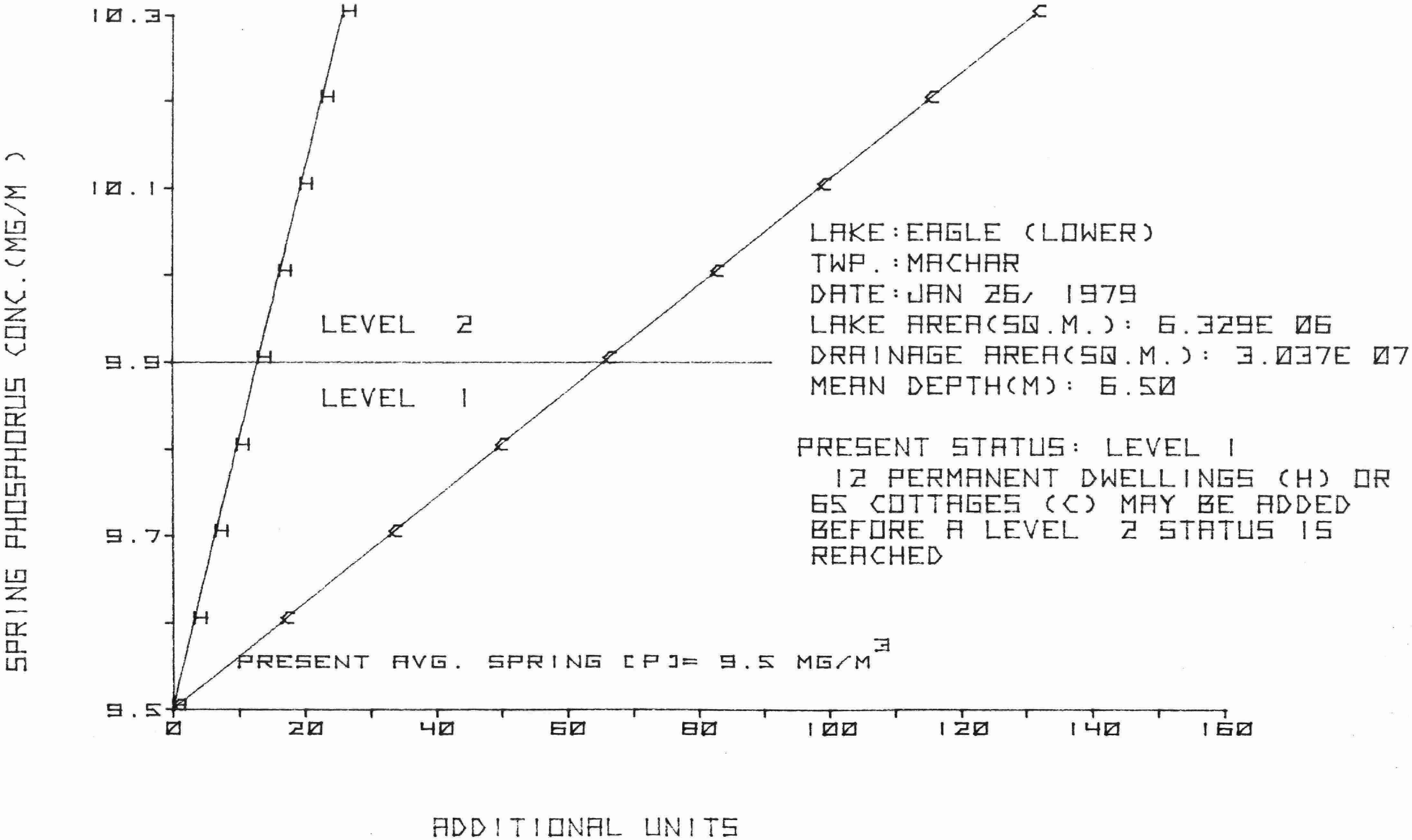
Actual Phosphorus Loading(mg/sq.m/yr): 151.73
Actual Phosphorus Supply(kg/yr): 960.30

MEASURED SPRING PHOSPHORUS CONCENTRATION(mg/cu.m): 9.5

Theoretical Phosphorus Loading(mg/sq.m/yr): 114.18
Theoretical Phosphorus Supply(kg/yr): 722.63

THEORETICAL SPRING PHOSPHORUS CONCENTRATION(mg/cu.m): 7.1

NORTHEAST REGION M.O.E.
LAKE DEVELOPMENT CAPACITY AFTER DILLON'S MODEL



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